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TEMPERATURE PROFILES OF RAIL TRANSPORTED ORDNANCE. PART 1. DESE--ETC(U)

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NWC TP 4917, Part 1

(12)

Temperature Profiles of Rail Transported Ordnance
Part 1. Desert Environment

by
Howard C. Schafer
Range Department

APRIL 1978

Naval Weapons Center
CHINA LAKE, CALIFORNIA 93555

Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

FOREWORD

This report presents results of environmental data measurements of ordnance-loaded rail cars in extreme desert temperatures from 1970 through 1977 by the Naval Weapons Center, China Lake, California. The work was sponsored by the Naval Air Systems Command under AIRTASK A03W3300/008B/31300000.

Kenneth Katsumoto has reviewed this report for technical accuracy.

The work described here in Part 1 is a continuing effort. Future reports in this series will be forthcoming as time and funding allow.

Approved by
C.J. DI POL, *Head (Acting)*
Range Department
1 October 1977

Under authority of
W.L. HARRIS
RAdm., U.S. Navy
Commander

Released for publication by
R.M. HILLYER
Technical Director

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(U) *Temperature Profiles of Rail Transported Ordnance. Part 1. Desert Environment*, by Howard C. Schafer. China Lake, Calif., Naval Weapons Center, April 1978. 78 pp. (NWC TP 4917, Part 1, publication UNCLASSIFIED.)

(U) The Naval Weapons Center has been involved in the measurement of ordnance temperatures since 1964. This report describes conditions experienced by ordnance-carrying rail stock in extreme desert environments during the period 1970 through 1977. Results of temperature measurements are given, and cumulative probability figures that are usable in predicting temperatures that are likely to be experienced by ordnance-loaded boxcars and flatcars are presented.

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To convert customary units to metric units in this report, the following table may be used.

Multiply	By	To get
Inch	25.4	Millimeter
Foot	0.3048	Meter
Pound	0.4536	Kilogram
mph	1.609	km/h
°F	$(t_{°F} - 32)/1.8$	°C

BACKGROUND

The transport of material via railroad has long been a reality. A common assumption is that railroads are as well situated on a worldwide basis as are the dirt track "highways." It is also commonly assumed that trains run on schedule even during and after great cold spells and storms. By consulting an atlas one can see that it could be more factually assumed that the major rail networks are to be found in the more populated and meteorologically temperate areas of the globe. Alaska, for example, has only one railroad, from Anchorage to Fairbanks. Even with its experienced section hands, the line is hard pressed to keep its schedule or even keep its equipment functional during the winter months. This example is not meant to downgrade the efforts of the Alaska railway, but to point out that even in this day and age the "iron horse" is not a commonplace item on a universal basis in the more meteorologically extreme reaches of the earth.

Using the general assumption that the major railways can be found in the more populated and meteorologically temperate zones of the world, then this would seem the logical situation to examine in terms of what is happening to ordnance and materials being transported in railroad boxcars. Specifically, it was desired to determine what conditions are experienced by ordnance-carrying rail stock in extreme desert situations.

INTRODUCTION

The Naval Weapons Center (NWC) first became involved in the measurement of railroad boxcar temperatures during the summer of 1964. Boxcars loaded to weight capacity with trinitrotoluene (TNT) blocks were being readied for shipment at the Naval Ammunition Depot (NAD), Hawthorne, Nevada, and NWC was tasked to measure the temperature regime experienced by these cars while awaiting dispatch. The only definitive similar work done prior to this was in conjunction with foodstuffs.[1]

Measurement work was continued for a time during 1965 at NWC/China Lake. However, these efforts were temporarily discontinued pending acquisition of additional boxcars and development of a comprehensive philosophy of measurement. Work at NWC recommenced in 1970 and data accumulation continued through 1977.

[1] Quartermaster Research and Development Command (now the Army Engineer Topographic Laboratories, Fort Belvoir). *Occurrence of High Temperatures in Standing Boxcars*, by W. L. Porter. Natick, Mass., QRDC, February 1956. (Report EP-27, publication UNCLASSIFIED.)

The NAD/Hawthorne and NWC/China Lake measurements are detailed in Appendices A and B, respectively. Appendix C provides a correlation of the NWC data as applicable to a specific time frame at NAD/Hawthorne. The primary purpose of this report is to present, in a summary statistical manner, the data accumulated from the extensive NWC measurement series. These data are presented in a form meant to provide ordnance designers and/or shippers with the probable chance of exposure in a pure desert environment during any given period.

INSTRUMENTATION

THERMOCOUPLE CONSTRUCTION

All thermocouples are of the copper-constantan type (Type T). The hot junction for internal measurements is a welded or silver-soldered 1/16- to 1/8-inch-diameter ball. The surface thermocouples for the ARN-6 radio container or bomb skin are of two types. The most universal and easiest to install is the area averaging type which consists of a 0.005-inch thick, 1/4-inch square copper plate. The constantan wire is silver soldered to one corner and the copper wire to another corner and the assembly is attached to the area of interest with epoxy. Early in this type program these units were only taped to the surface of interest. This attachment method is satisfactory for short times at locations where the installation will be regularly inspected for thermocouple lift off. However, for long term, "abandoned" measurement jobs, this attachment method can lead to trouble. The other, more time consuming method was to drill two small holes about 1/8- to 1/4-inch apart in the surface to be measured, place the copper wire in one and the constantan wire in the other, silver solder the wires in place, and then grind down the solder joints so that the surface is again smooth and repaint. A comparison of the data from these two types of installation indicated that there is no significant accuracy difference for this application.

RECORDER

At the China Lake site, a 200-channel data logger was put into operation in May 1970. This digital tape instrument is still in the "trial" period of operation. Compared to the Honeywell Model 15 recorders it is more accurate and vastly more complicated and sensitive. Its out-of-laboratory usability has yet to be proven. However, it can run up to 5 or 6 months on a single tape at an hourly sample rate, and the tape can be input directly to the computer for quick reduction. (On the other hand, reduction of the more reliable Honeywell Model 15 Recorder charts is strictly a manual operation.)

After the loss of five winter months of data during a malfunction of the rewind mechanism, it was decided to parallel important data channels with the more cumbersome Honeywell recorder. In this manner, the data herein reported for November and December 1970, and January, February, and March 1971 were salvaged. In short, the more sophisticated instrumentation is superior in a situation where a "babysitter" is constantly available. For off-station primitive conditions, it is wise to sacrifice sample speed, some accuracy, and ease of data reduction for usable data.

Because of the relatively slow sample rates necessary, slow temperature changes encountered, and the low narrow band of temperature sampled in this type of sequence, the normal thermocouple and instrument errors were either not encountered, or were classified as "in the noise."

USING THE CURVES

The following overview will provide the reader with a basic understanding of how to use the cumulative probability curves (Figures 1-31). For a more in-depth review users should refer to a good book on statistics.

The curve is compiled by adding together all the hours which have the same temperature value. Then, starting from the coldest group of hours and progressing to the hottest, the hours are added (or accumulated) and normalized before each accumulated value is presented graphically. Thus all the 75°F temperature hours are added to all the hours with a temperature of less than 75°F. This accumulated number of hours is then divided by the total number of hours in the complete sample. Therefore, to read a cumulative probability value (such as 0.75) the corresponding temperature, or less, is said to be experienced 75% of the time covered in the figure. To be more specific, refer to Figure 1. The temperature which corresponds to the 0.7 cumulative probability is 85°F. This means that, for the period from 1 June 1970 through 14 February 1974, that bomb experienced a temperature of 85°F OR LESS for 70% of the time of exposure.

To find the 3 sigma hot point on the curve, it must be remembered that 3 sigma is equivalent to 99.7% of the area under a gaussian distribution curve. Therefore, 0.3% of the area under the curve is not covered. This area must be divided into two parts since there are plus and minus 3 sigma values for any gaussian distribution. Therefore, 0.15% must be added to the 99.7% value making the plus 3 sigma point 99.85% (or, on our plots, .9985). Obtain the temperature corresponding to .9985 (or .0015) and you have the 3 sigma values.

It is generally safe to use any value taken from the horizontal portions of the curve. The more vertical (steeper) the curve, the more data points have been accumulated. A more horizontally flattened out curve has fewer data points.

CUMULATIVE PROBABLE CHANCE OF EXPOSURE

Previous work by the author and others can only indicate the broad scope of the thermal exposure to be expected in a boxcar. The statistical data presented here will provide the designer or shipper with a chance of occurrence for any temperature value chosen. The data used here were taken at China Lake, California, which is located in the Mojave Desert (see Appendix B). Typical meteorological information for this area is available from the National Weather Records Center, Asheville, North Carolina, under the code name Inyokern. Inyokern is a class A weather station located about 10 miles west of the boxcar-flatcar exposure site (Figures 32 and 33), with an 800-foot high (AGL) hill between the two locations.

The date for any one NWC data point will not be identified more precisely than to indicate the season of the year, which means the Inyokern weather data can only be correlated in a statistical manner. Therefore, the microclimatic differences between the two locations tend to have less meaning.

Because the thermal response of almost any ordnance load when packed inside a boxcar or piggyback van will tend to be weight-limited, 1000-pound bombs were chosen as an easily measured load matrix. For a volume-limited cargo, the ARN-6 Korean war vintage aircraft radio navigation receiver load data presented herein will be used as the measurement matrix. Two groups of curves are presented, one for the designer and one for the shipper. The designer must design as if his material will be in transit through the desert during any given day or season of the year. Therefore, he is interested in a composite curve of all 8,760 hours per year, or multiple thereof. Thus, when he assigns a design temperature to the material for shipment in hot weather, he will have a probable chance of occurrence number that will be based on the complete yearly cycle rather than on a piece of that cycle.

In contrast, the shipper knows when, within a 3-month period, his material will be going across the desert. Therefore, he is more interested in a set of seasonal curves. (Foodstuffs can be very susceptible to degradation even at the more elevated meteorological air temperatures encountered in the summer on the desert. However, very slight damage might be expected during the other nine months of the year.)

Cumulative probability figures for the boxcar and flatcar-with-van are summarized in Tables 1 and 2, respectively. The Table 1 data, in the main, are usable for predictions of any existing fully enclosed boxcar, whether constructed of metal or wood. These temperature data were taken in an aluminum colored boxcar in a stationary location. In the author's estimation, these two facts of exposure, coupled with the location of exposure, tend to result in reliable universal hot climate data. The temperature data taken inside the piggyback vans can be regarded as extreme. The vans were covered with oxidized Army olive drab flat paint; therefore, they should not have reflected much solar energy at any time.

TABLE 1. Boxcar Summary of Cumulative Probability Figures.

Fig.	Load	Channel	No. hours	Season	Position in car
1	bombs	97	29,087	all	NW corner
2	bombs	97	8,824	summer	NW corner
3	bombs	99	29,087	all	Center of load
4	bombs	99	6,154	spring	Center of load
5	bombs	99	8,824	summer	Center of load
6	bombs	99	6,157	winter	Center of load
7	bombs	99	7,952	fall	Center of load
8	amb. air	101	29,087	all	Top of car
9	amb. air	101	8,824	summer	Top of car
10	ARN-6	103	29,087	all	SW corner
11	ARN-6	103	6,154	spring	SW corner
12	ARN-6	103	8,824	summer	SW corner
13	ARN-6	103	7,952	fall	SW corner
14	ARN-6	103	6,157	winter	SW corner
15	ARN-6	105	29,087	all	Center of load
16	ARN-6	105	8,824	summer	Center of load

TABLE 2. Railroad Flatcar With Van—Summary of Cumulative Probability Figures.

Fig.	Load	Channel	No. hours	Season	Position in van
17	bombs	110	29,087	all	Center
18	bombs	110	8,824	summer	Center
19	bombs	111	29,087	all	South end
20	bombs	111	6,154	spring	South end
21	bombs	111	8,824	summer	South end
22	bombs	111	7,952	fall	South end
23	bombs	111	6,157	winter	South end
24	amb. air	112	29,087	all	Under roof
25	amb. air	112	8,824	summer	Under roof
26	amb. air	115	29,087	all	Under roof
27	ARN-6	116	29,087	all	Top of load
28	ARN-6	116	6,154	spring	Top of load
29	ARN-6	116	8,824	summer	Top of load
30	ARN-6	116	7,952	fall	Top of load
31	ARN-6	116	6,157	winter	Top of load

PHILOSOPHY OF MEASUREMENT

The first assumption was that the most extreme thermal exposure for a given set of meteorological conditions would be experienced if the boxcar was not moving. The reasoning was that, in the hot desert, the motion of the boxcar through the surrounding air would change the primary heating mode, or thermal forcing function, from radiation to forced convection. Since the radiation-induced temperature of the boxcar's skin is higher than the ambient air temperature, the relative motion of air and boxcar could only result in cooling of the skin. Instead of a possible boxcar roof outside skin temperature of 140-170°F, the convection temperature would be only 100-115°F. If the roof and walls of the boxcar are "cool," then the load inside cannot exceed that value. However, if the car is standing still in the cloudless, windless desert summer sun, temperatures above the meteorological values can be and are experienced.

On the cold side, it was reasoned that a stationary boxcar will radiate to the clear cold sky with possible cooling of the walls and roof as much as 5-8°F below that of the meteorological air temperature. When moving, a boxcar will gain some heat via moving parts and conserve heat because of the mass of the train. Also, cold spells seem to bring with them a more than normal thermal turbulence. Previous work done by the author indicated that meteorological air temperature can vary 19-25°F an hour. A moving boxcar would travel through a cold air sump and continue on to "warmer" elevations or geographical locations. If a boxcar were stationary in a cold sump, then it would experience lower than outside air temperatures.

The next step was characterization of the boxcar load. These were classified as volume-limited and weight-limited. The volume-limited load would be described as items so light and bulky that the boxcar is packed full. Electronics materials are items that would tend to be in the volume-limited category. Weight-limited loads often consist of items so heavy that the boxcar's load limit is reached when the boxcar is still relatively empty. Most, if not all, ordnance will tend to fall into the weight-limited category.

The shipment of military ordnance is done in a special lot of ammunition cars. These have the designator USAX, USNX or DODX. The USNX and DODX cars are painted aluminum in color. (The boxcars used in the NWC measurements were painted with aluminum-filled Rust-oleum brand paint which is very reflective to the eye.) The air temperature inside aluminum painted boxcars may be different from that of the conventional rust-red painted cars. But, such a difference would only occur when radiation both into and out of the car is a major factor. Since radiation is the primary heating and cooling mode only when there is no relative velocity between boxcar and air, it would seem that, under way, the difference should be small. Also, the total band of boxcar exposure should be lowered slightly, not just the "hot" end. For the aluminum painted cars, the cold exposure should be slightly cooler due to reflection of the incoming solar radiation during winter.

RESULTS

The range of temperature values to be expected in rail shipped ordnance or material is quite limited. Referring to Figures 1-31, it can be seen that the highest materials temperatures were experienced in the volume-limited load situation. The three-year high temperatures

reported for one hour or less were 128°F (Figure 10) in the boxcar (channel 103) and 125°F (Figure 17 (channel 110)) in the piggyback vans. Notice that the shape of the cumulative probability curves are close to that of a gaussian distribution. This feature is probably caused by the thermal time lag between high solar radiation and load response. This would tend to dampen out the high temperature seen during the peak of the day, but also raise the nighttime low temperature due to the time necessary for the boxcar load to lose heat. It can be generally said then that nature tends toward moderation, and the thermal lag is one such means toward moderation.

In contrast to the 3-year maximum material temperature of 128°F, in one of the vans the air temperature a few inches under the roof peaked out at 149°F. This is not an uncommon extreme temperature for air in close proximity to the top or southern top wall of a boxcar. For analytical purposes, a temperature of about 150°F might be tentatively used as a forcing function for calculation of possible material temperatures. Keep in mind, however, that this value is only one point in a diurnal cycle and will last less than one hour. Also, if the train were in motion, forced convection and the Bernoulli effect would cool the outside of the boxcar and evacuate the hot air from the interior.

A review of the cumulative probability curves presented herein indicates that, for either weight- or volume-limited loads, the envelope of maximum temperature exposure is between 128 and 100°F. Keep in mind, however, that there is generally a 3 to 7 day onset period to these maximum temperatures. In other words, unless the maximum meteorological conditions (no wind, high solar radiation, moderate to high air temperature) exist for 3 to 7 days, and the car is motionless during this time, then the high temperatures herein referred to as maximum will not be experienced.

As can be noticed from a comparison of data of all the channels, there is a temperature gradient through the boxcar or van. The air is stratified because the heat is applied from the top or roof. Since hot air rises, there can be little or no thermal syphon or mixing of different temperature air. Most of the heat transfer, therefore, must be by direct radiation from the roof and walls.

EXTENSION OF MEASUREMENT SERIES

The NWC measurement series reported in Figures 1-31 did not terminate in 1974. Rather, data are still being collected on a continuing basis because of litigation arising as a result of an explosive railroad incident in 1973. The data collected have been used to approximate the probable maximum ordnance temperature experienced by Tritonal-filled Mk 81 low drag bombs at NAD/Hawthorne, as discussed in Appendix C. It was, therefore, decided to continue the NWC measurements series at least until this litigation came to trial.

Data collected since 1974 have been spot checked to see if they correlate with what has been reported herein. Since no significant temperature values have been recorded in the post-1974 time period, the data reported herein for the high temperature excursions can be considered representative of the 1970-1977 time frame. This then expands the usable data base of thermal response to the desert quiescent boxcar high temperature forcing function to a

continuous 8-year period. Keep in mind that, even though this is not a full 11-year half solar cycle, it still represents a time span sufficient to provide the user with confidence that his material design or shipment probably will not experience conditions exceeding the response temperatures reported herein. If we do no more than multiply the channels of data herein reported times 8,760 hours per year times 8 years (10 X 8,760 X 8) it can be said that the total of over 700,000 data points will satisfy the concept of statistical infinity.

CONCLUSIONS

It can be readily seen that any shipment of military material, even in a pure desert environment, will have no chance of attaining an energy level nor soak temperature of 160°F. Figures 1-31 conclusively show that the top temperature to be expected is about 100-110°F, with an outside chance for temperatures of 130°F for one or two hours per decade on the skin of the box or shipping container. It must be reiterated that these remarks incorporate the situation of a "stalled" train on a hot-hot day in a pure desert environment. Also, data herein reported include that derived from an olive-drab painted piggyback van; therefore, the color of the rail car cannot significantly increase these findings. The author believes that maximum design temperatures for this event of the factory-to-target sequence should be as shown in Appendix A of MIL-STD-1670 ("Environmental Criteria and Guidelines for Air-Launched Weapons").

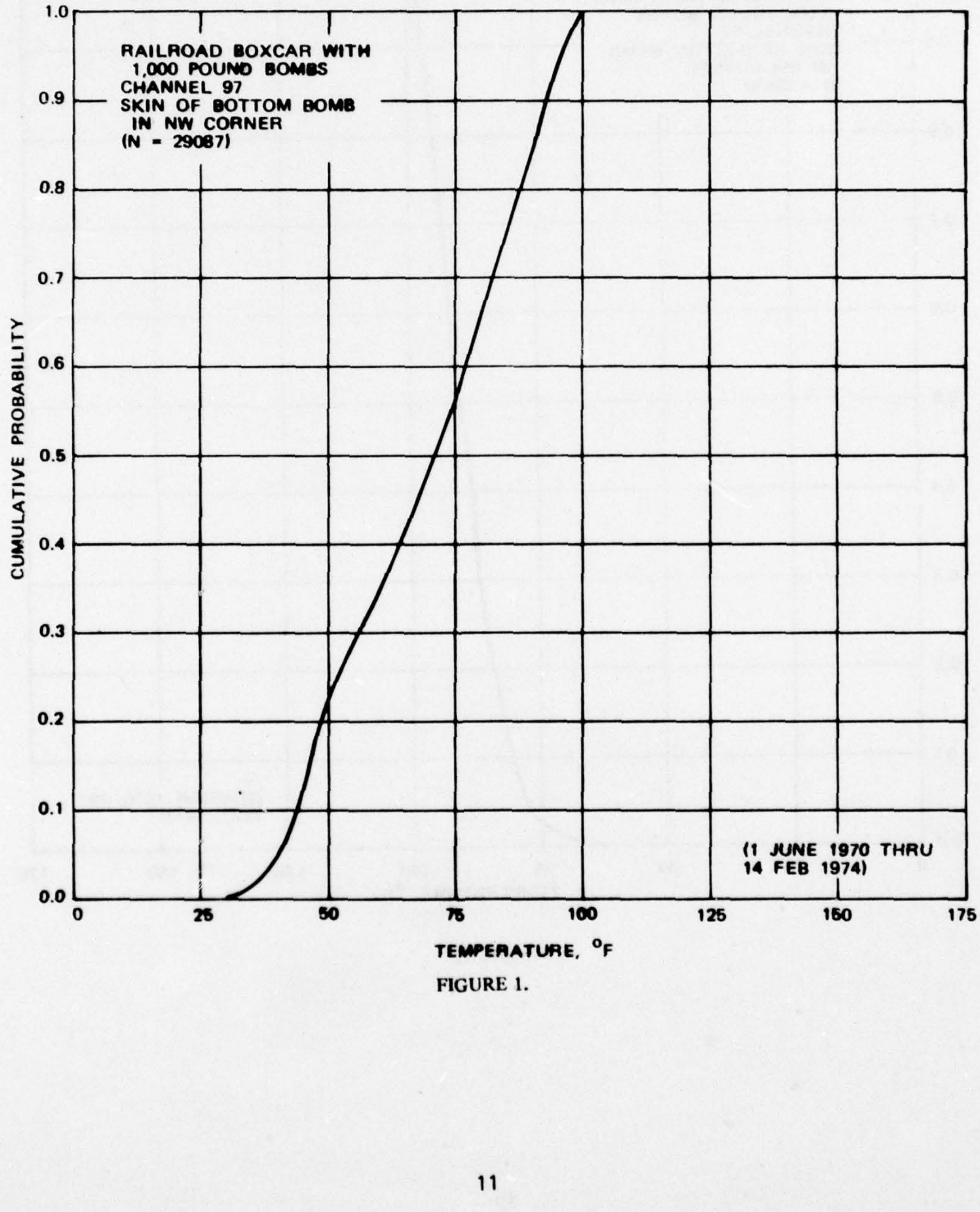

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 97
SKIN OF BOTTOM BOMB
IN NW CORNER
(N = 29087)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 1.

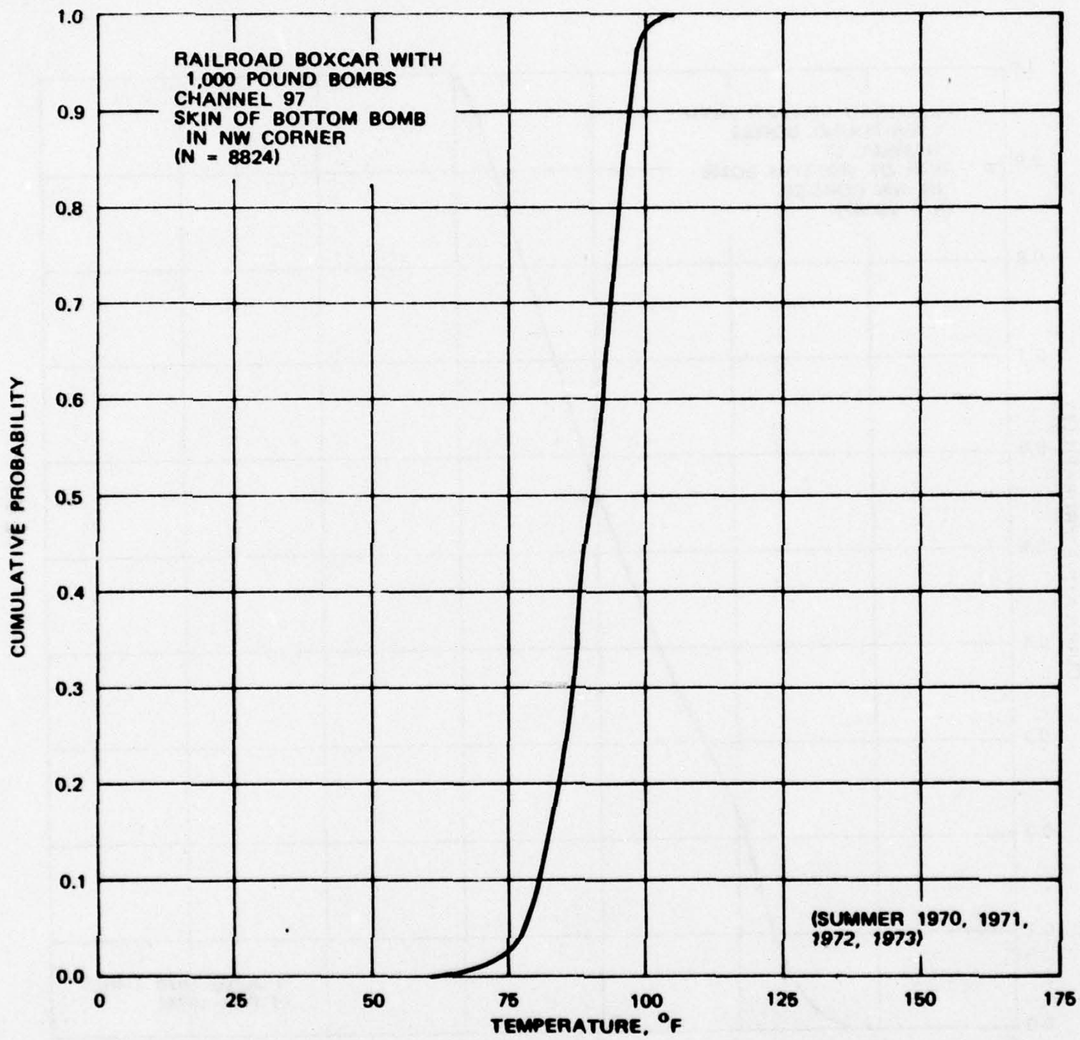

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 97
SKIN OF BOTTOM BOMB
IN NW CORNER
(N = 8824)
(SUMMER 1970, 1971, 1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 2.

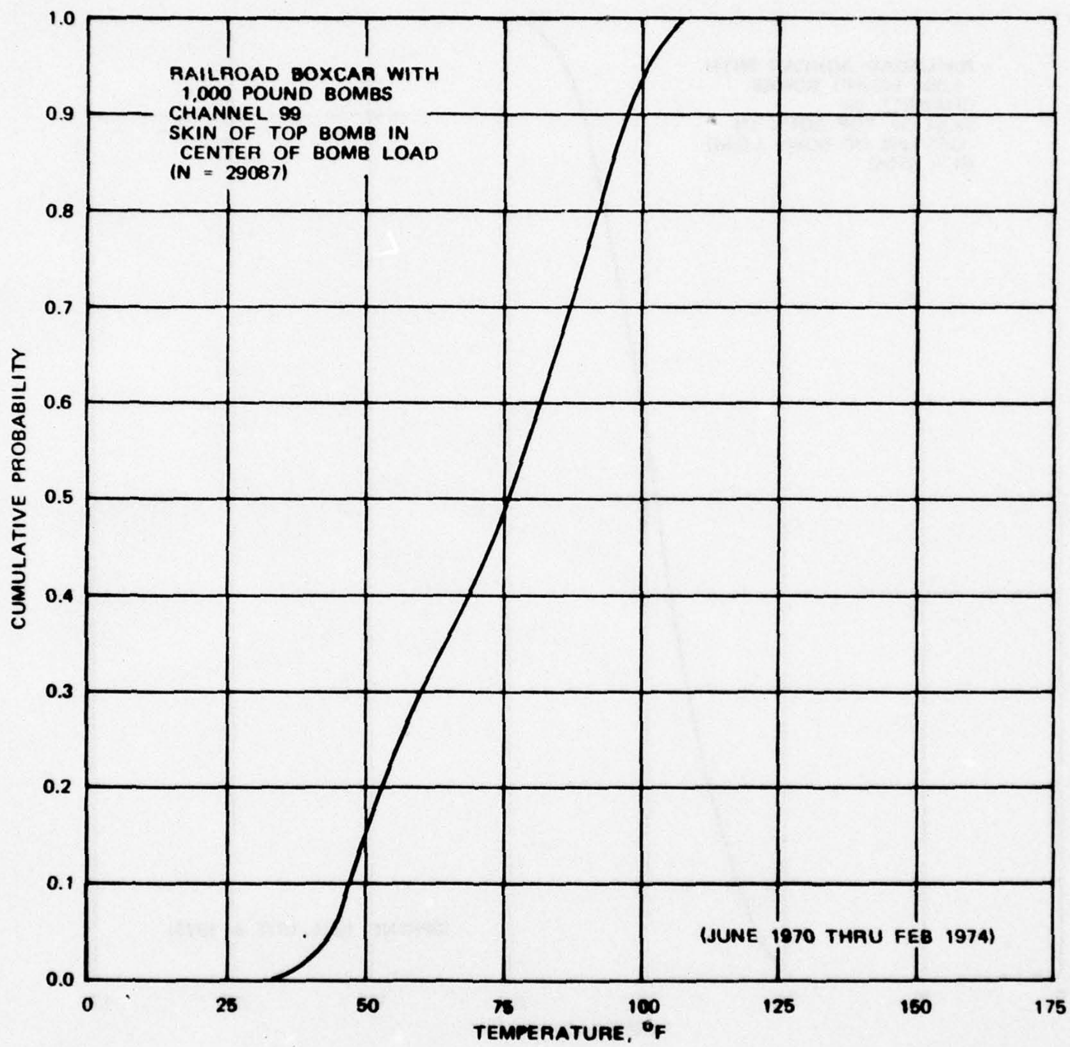
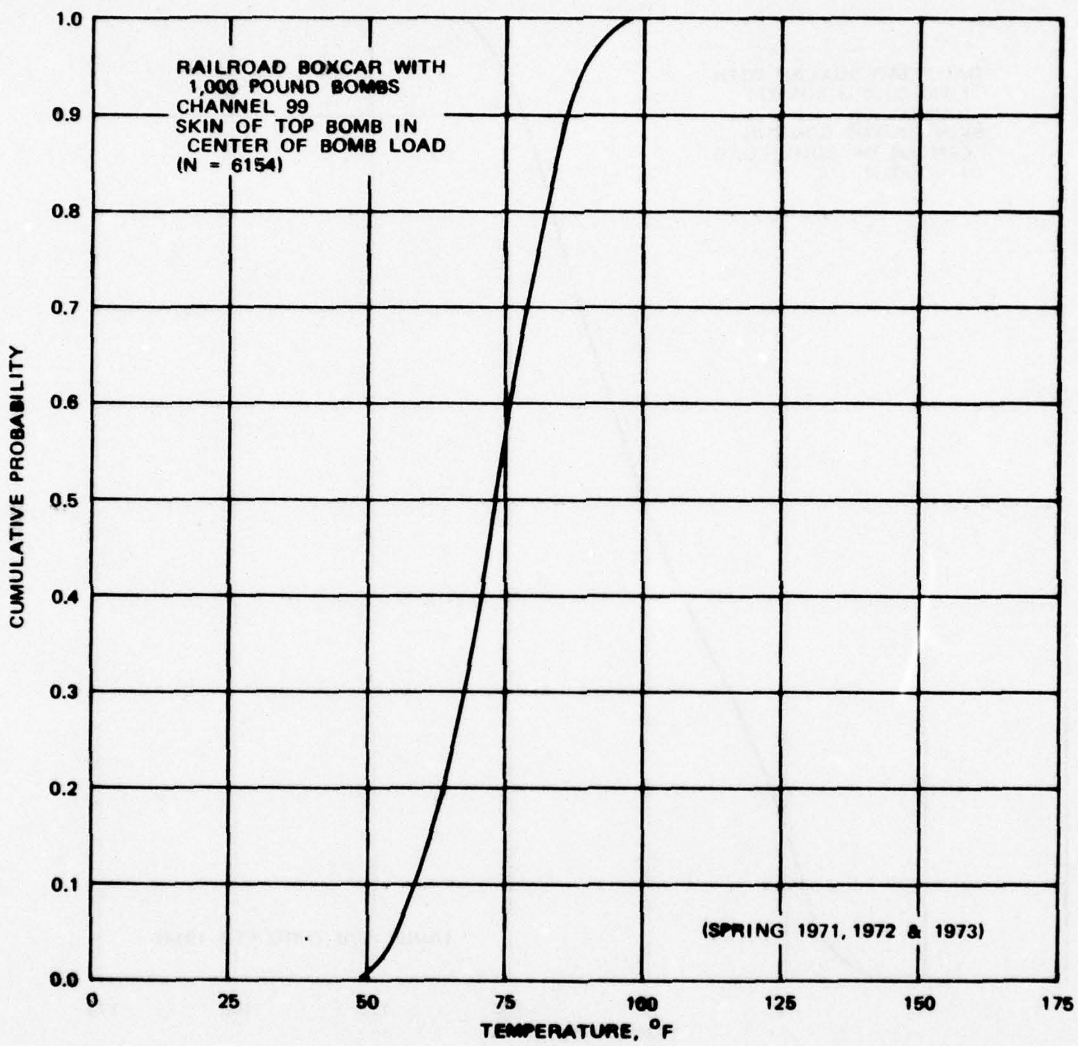

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 99
SKIN OF TOP BOMB IN
CENTER OF BOMB LOAD
(N = 29087)
(JUNE 1970 THRU FEB 1974)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 3.



RAILROAD BOXCAR WITH 1,000 POUND BOMBS
CHANNEL 99
SKIN OF TOP BOMB IN CENTER OF BOMB LOAD
(N = 6154)
(SPRING 1971, 1972 & 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 4.

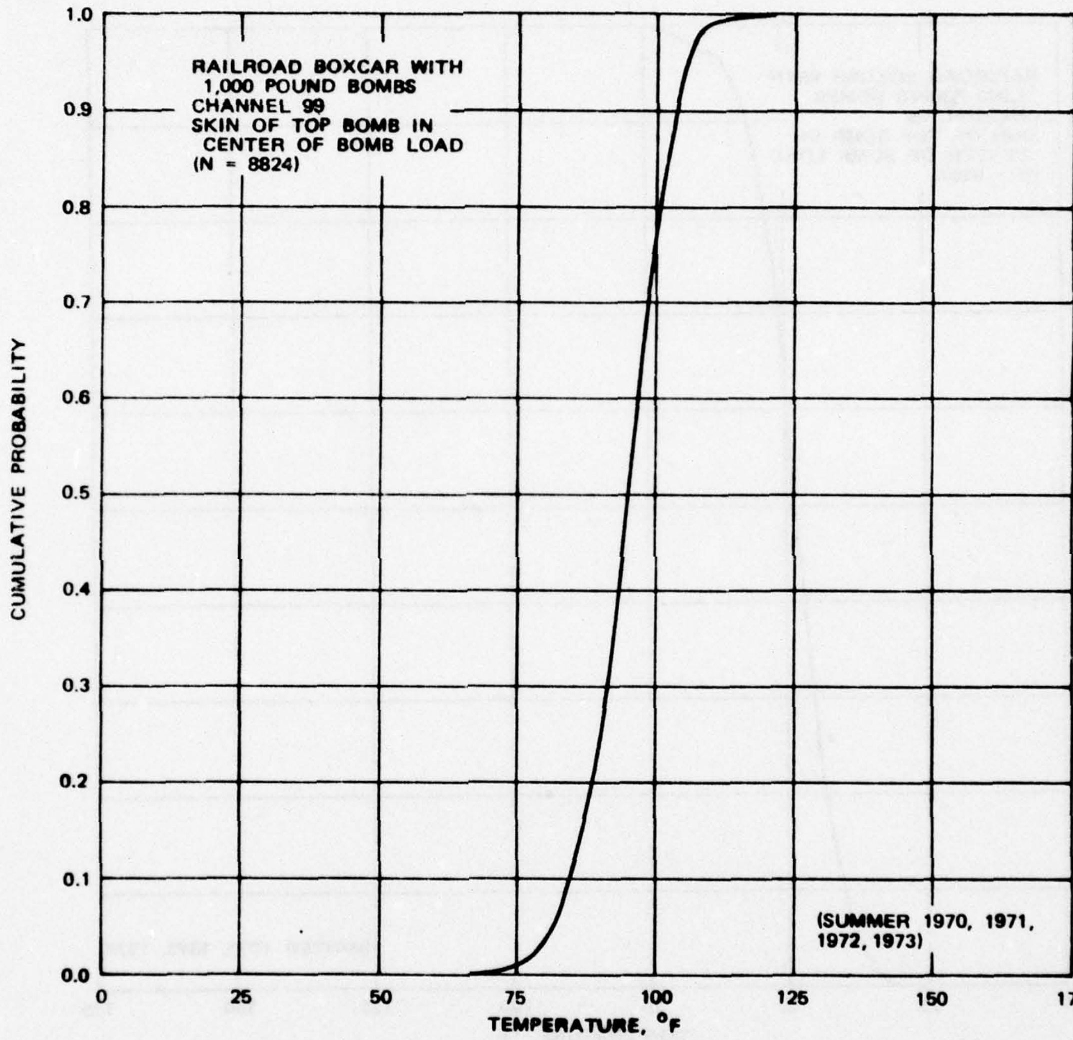

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 99
SKIN OF TOP BOMB IN
CENTER OF BOMB LOAD
(N = 8824)
(SUMMER 1970, 1971,
1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 5.

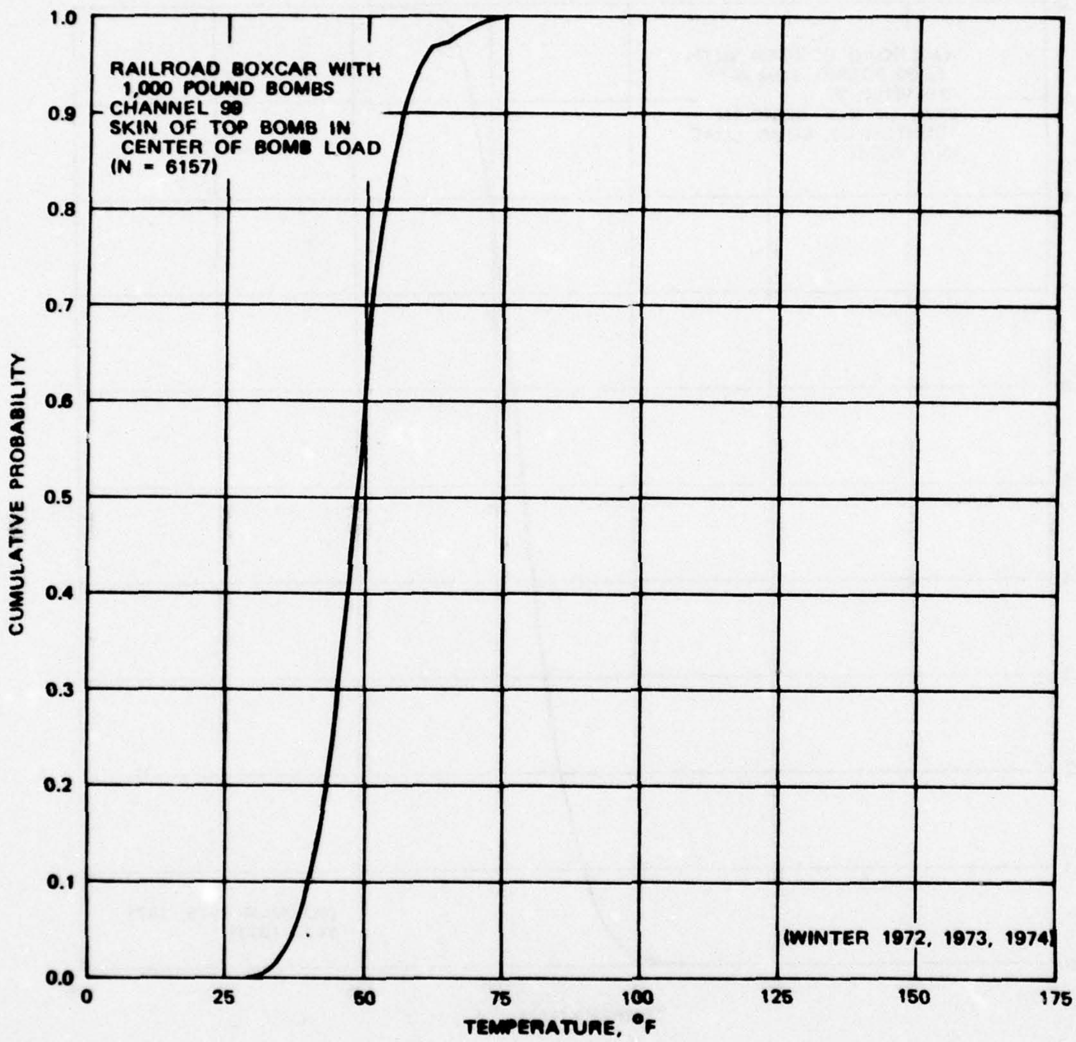

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 99
SKIN OF TOP BOMB IN
CENTER OF BOMB LOAD
(N = 6157)
(WINTER 1972, 1973, 1974)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 6.

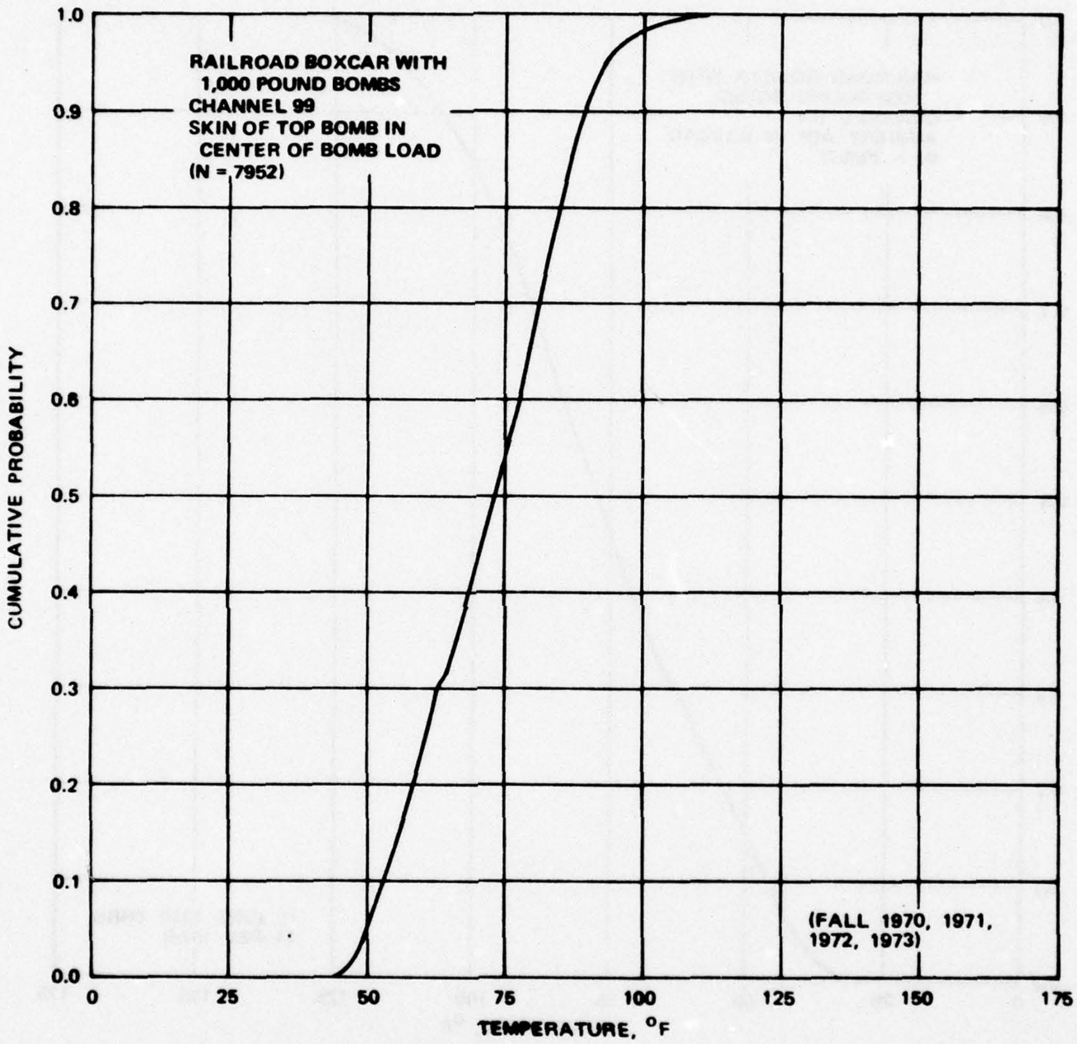

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 99
SKIN OF TOP BOMB IN
CENTER OF BOMB LOAD
(N = 7952)
(FALL 1970, 1971,
1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 7.

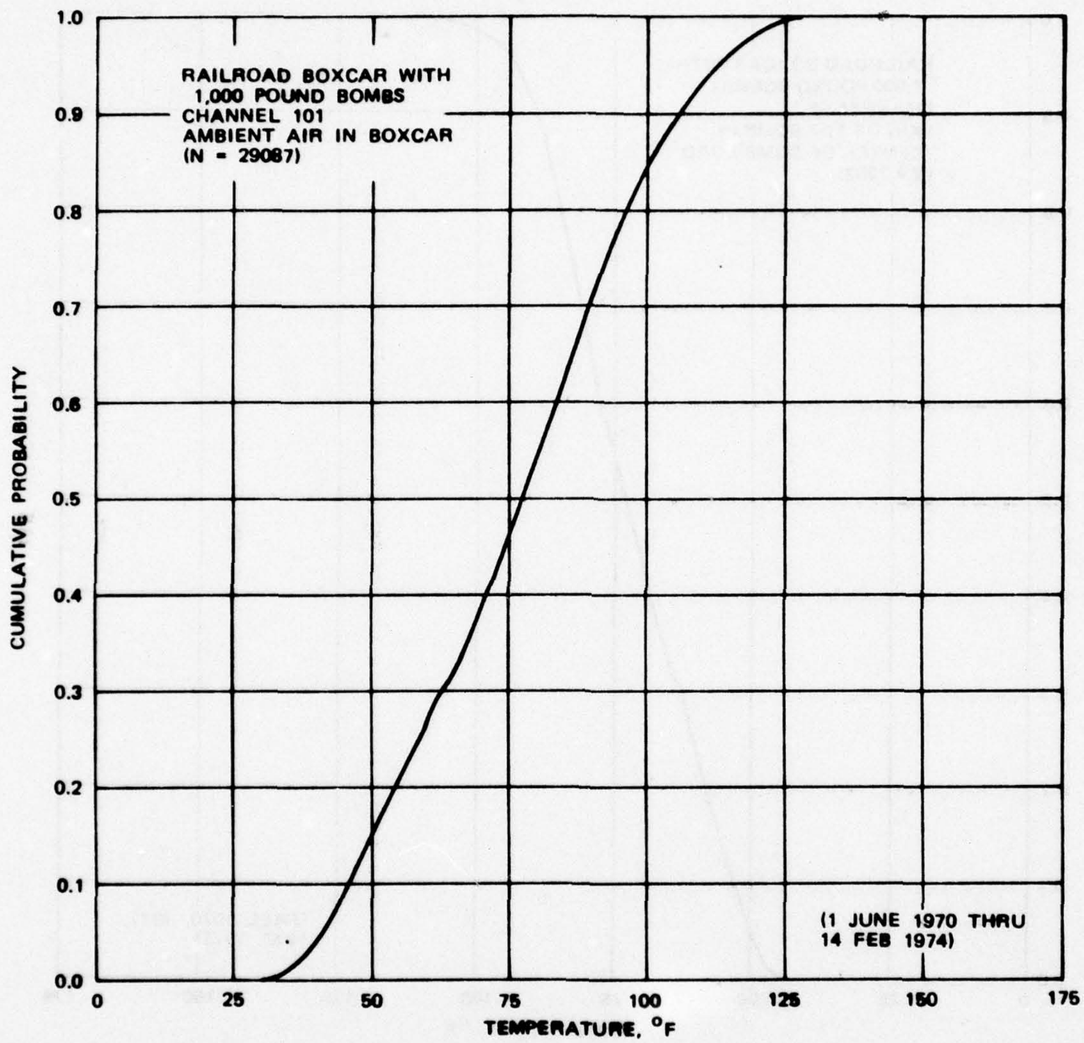
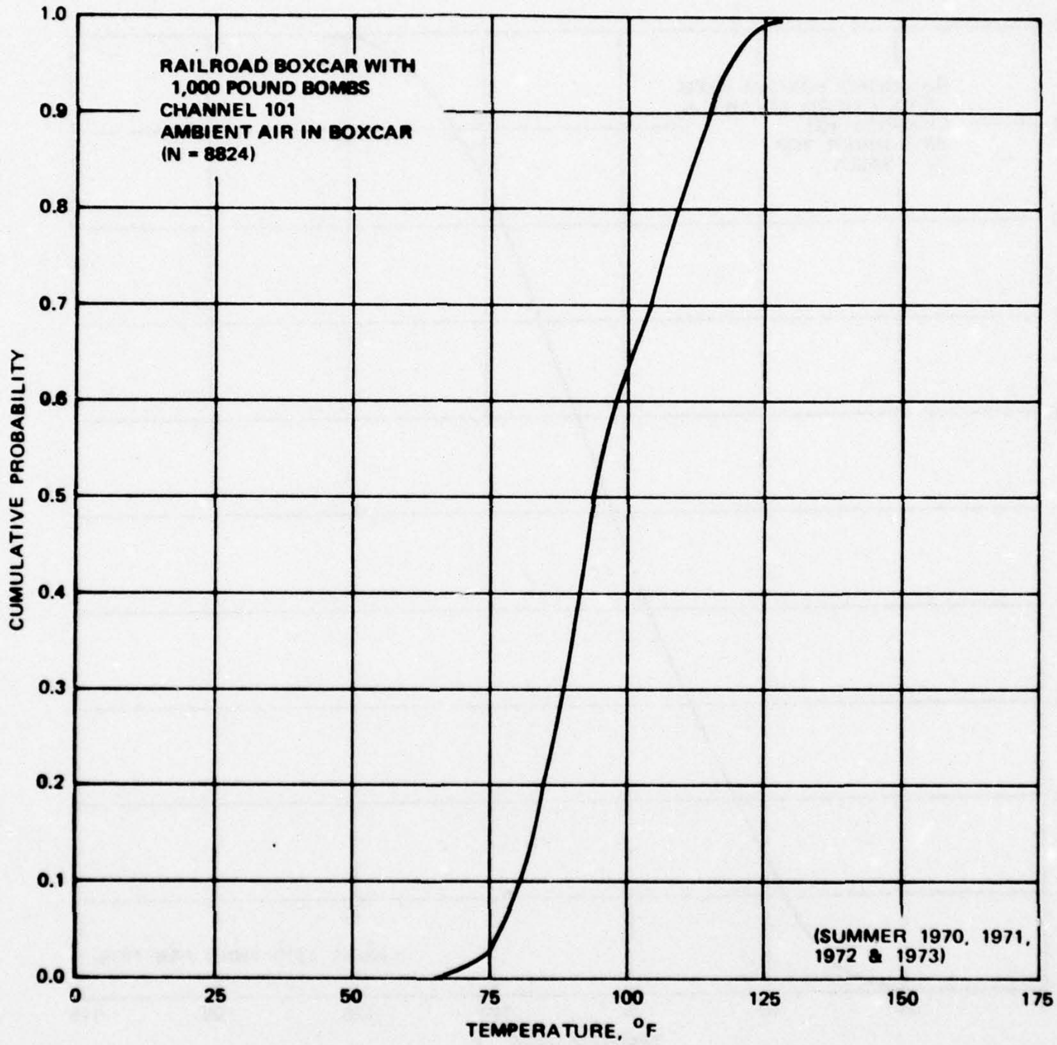

RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 101
AMBIENT AIR IN BOXCAR
(N = 29087)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 8.



RAILROAD BOXCAR WITH
1,000 POUND BOMBS
CHANNEL 101
AMBIENT AIR IN BOXCAR
(N = 8824)
(SUMMER 1970, 1971, 1972 & 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 9.

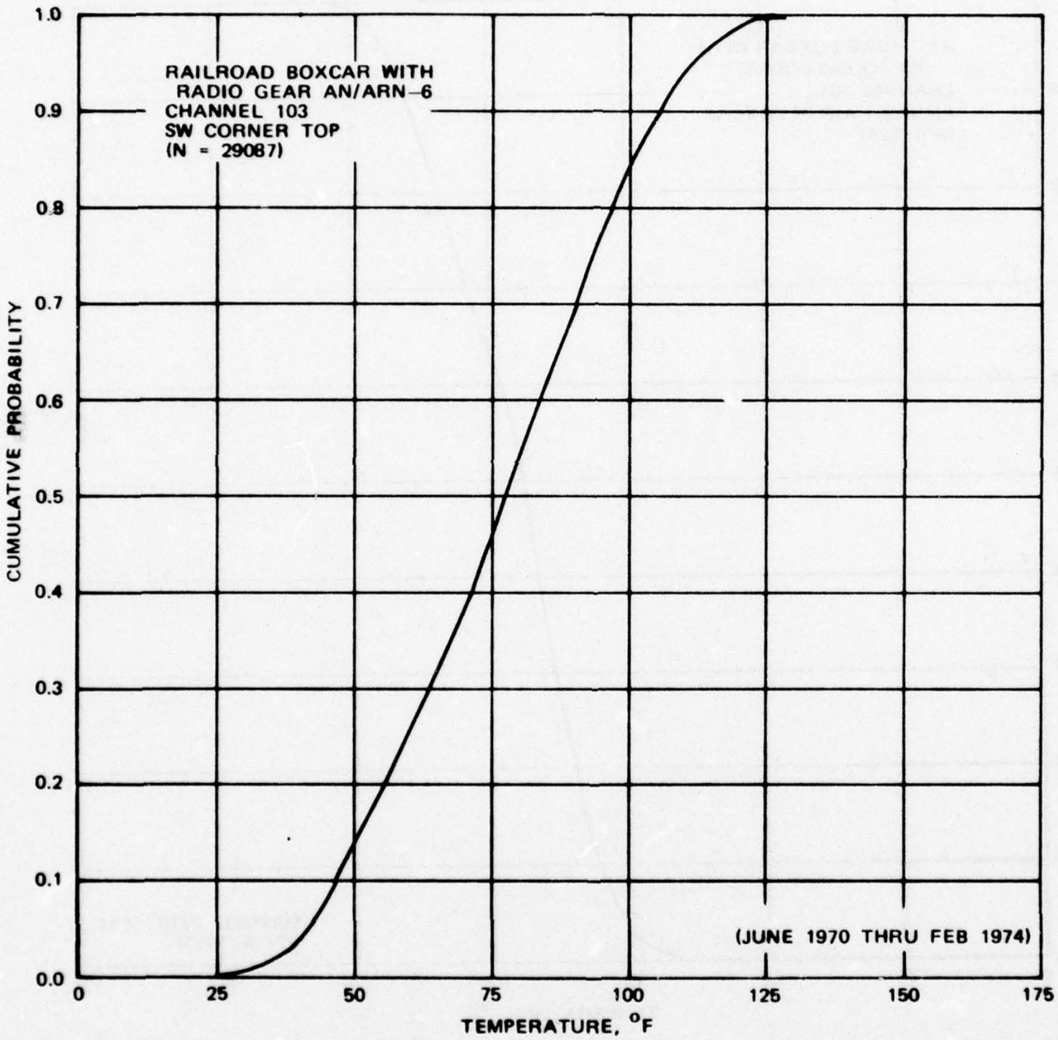

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN-6
CHANNEL 103
SW CORNER TOP
(N = 29087)
(JUNE 1970 THRU FEB 1974)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175

FIGURE 10.

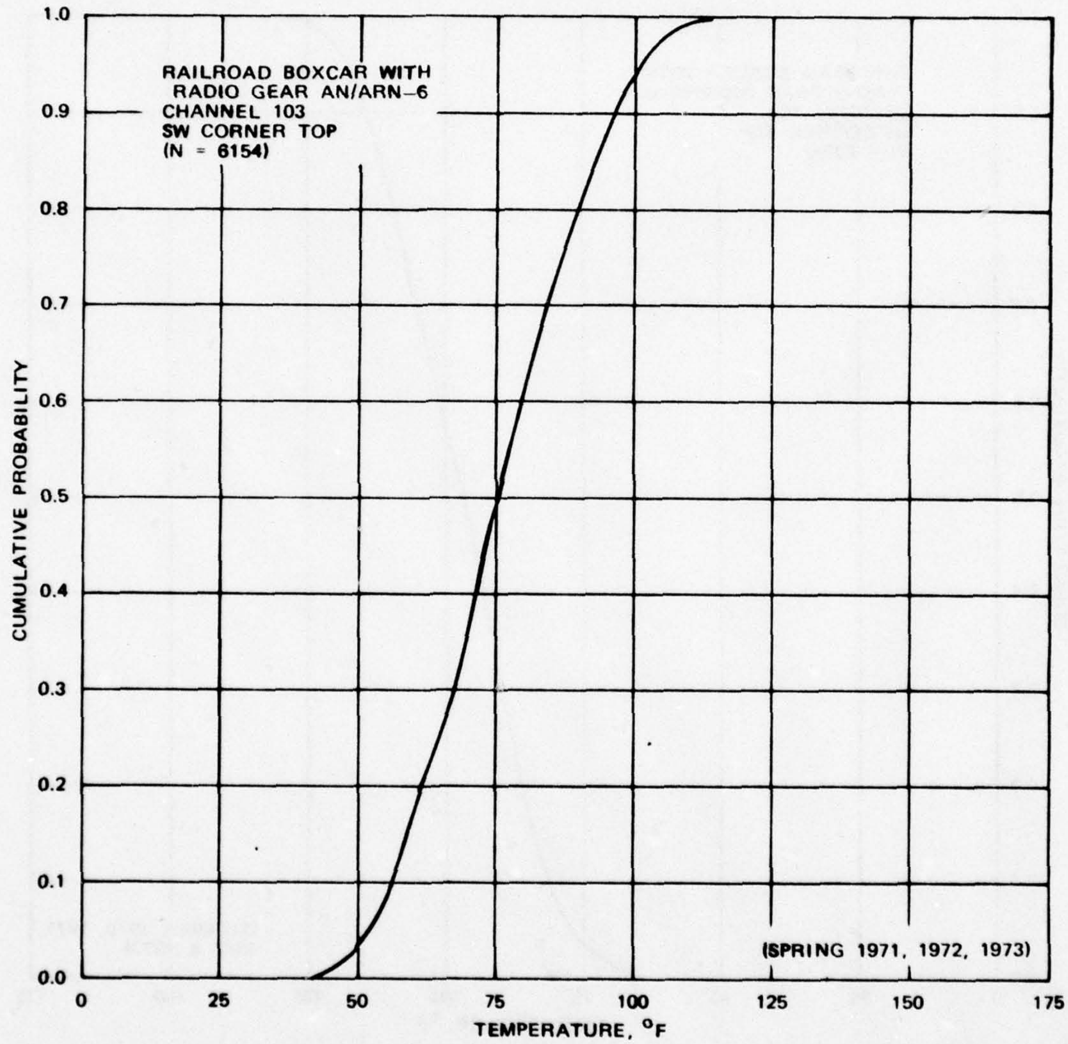

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CUMULATIVE PROBABILITY
RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN–6
CHANNEL 103
SW CORNER TOP
(N = 6154)
(SPRING 1971, 1972, 1973)
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 11.

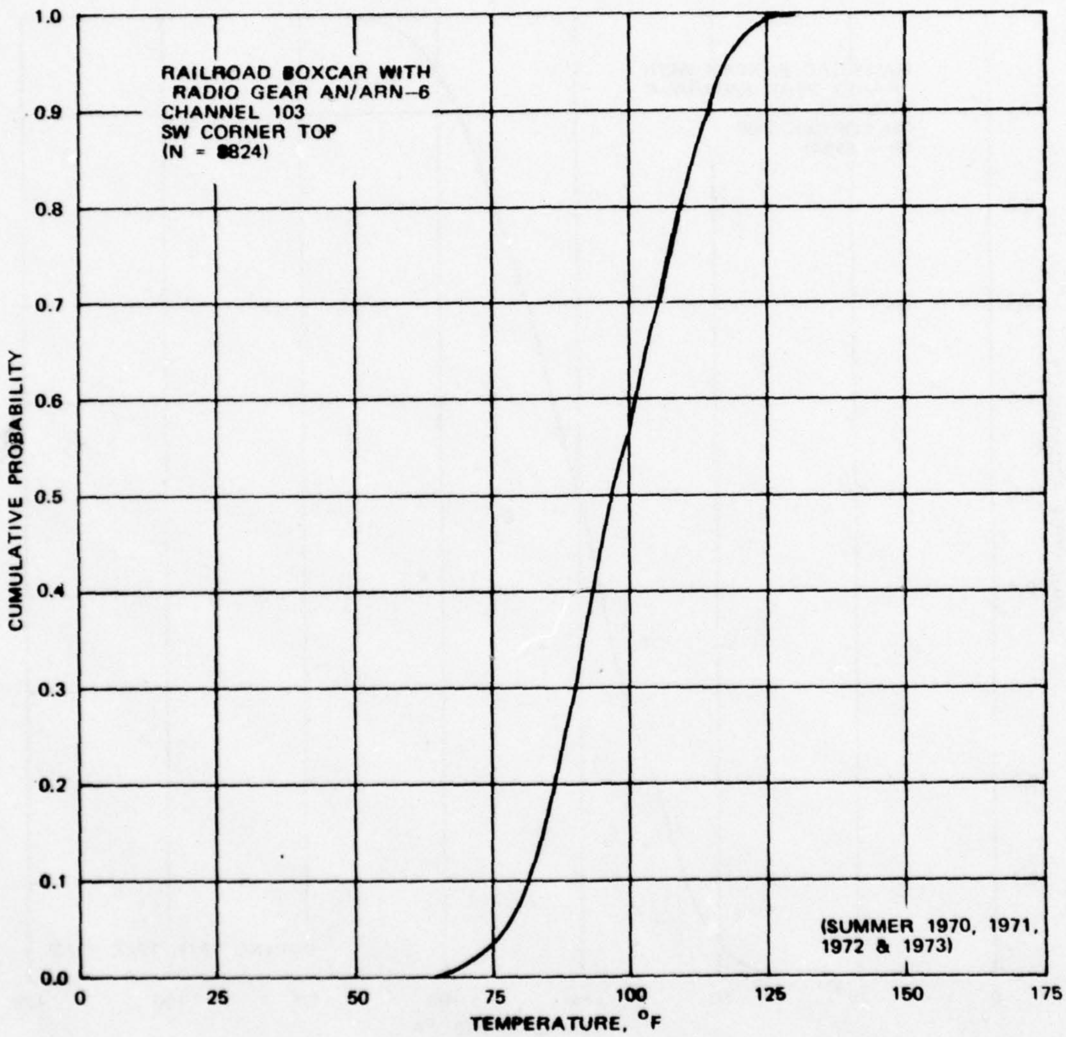

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN–6
CHANNEL 103
SW CORNER TOP
(N = 8824)
(SUMMER 1970, 1971,
1972 & 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 12.

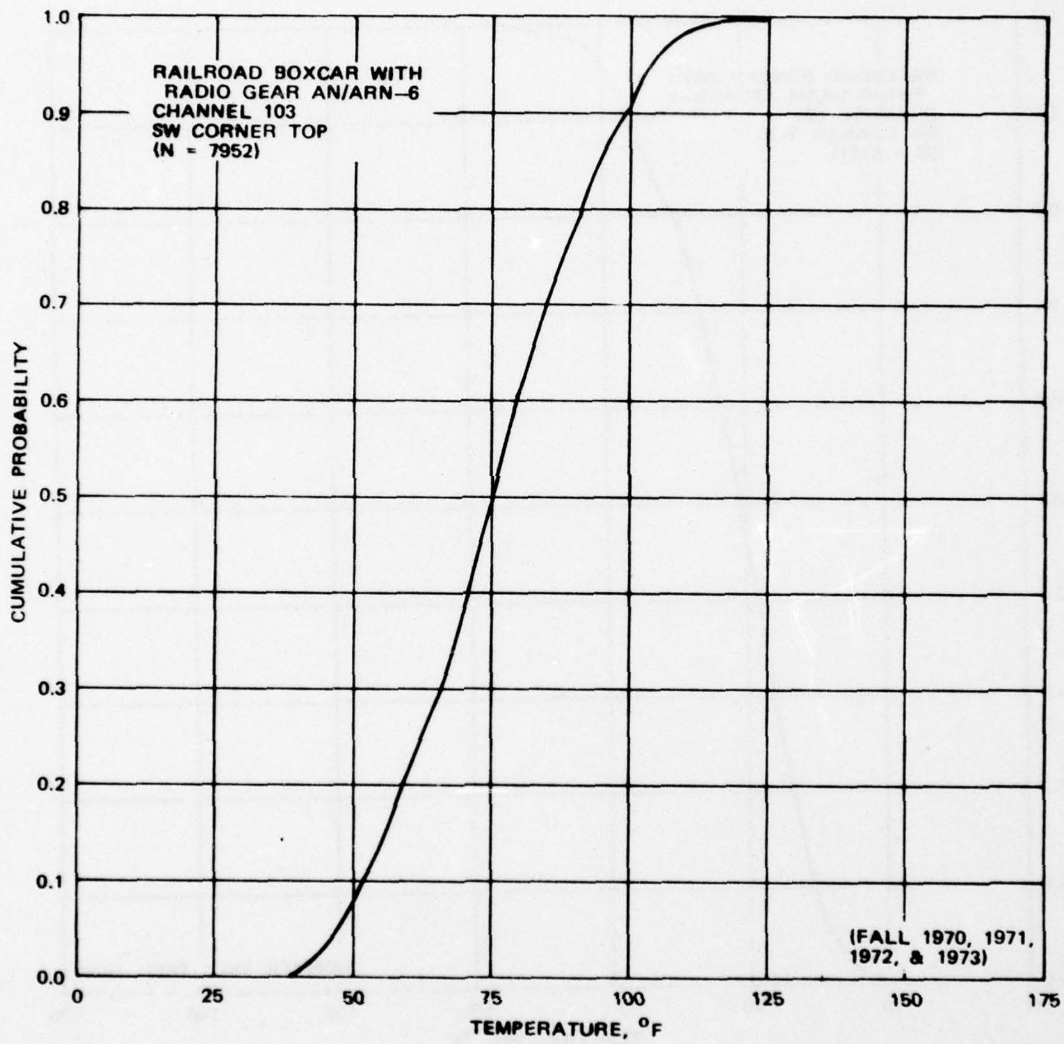

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN–6
CHANNEL 103
SW CORNER TOP
(N = 7952)
(FALL 1970, 1971,
1972, & 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 13.

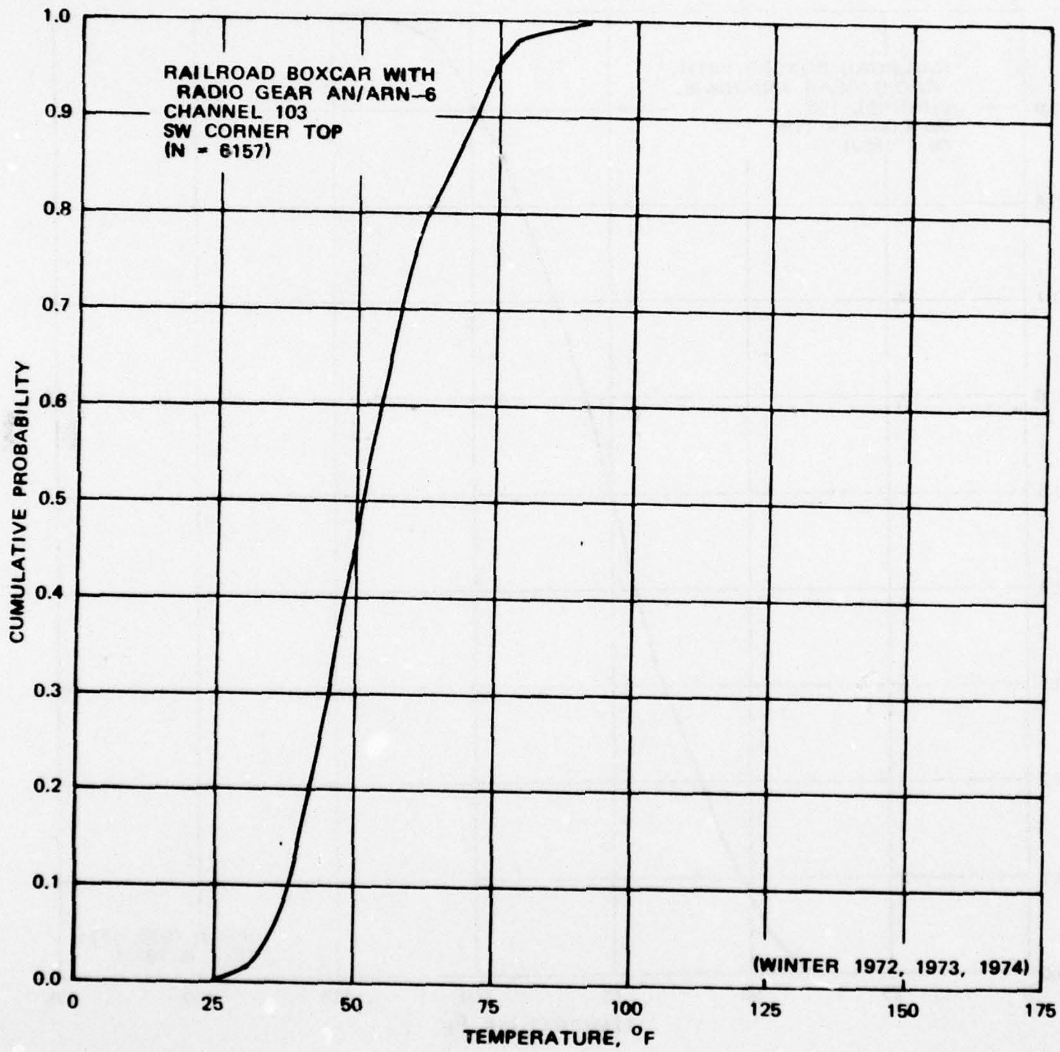

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN-6
CHANNEL 103
SW CORNER TOP
(N = 6157)
(WINTER 1972, 1973, 1974)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175

FIGURE 14.

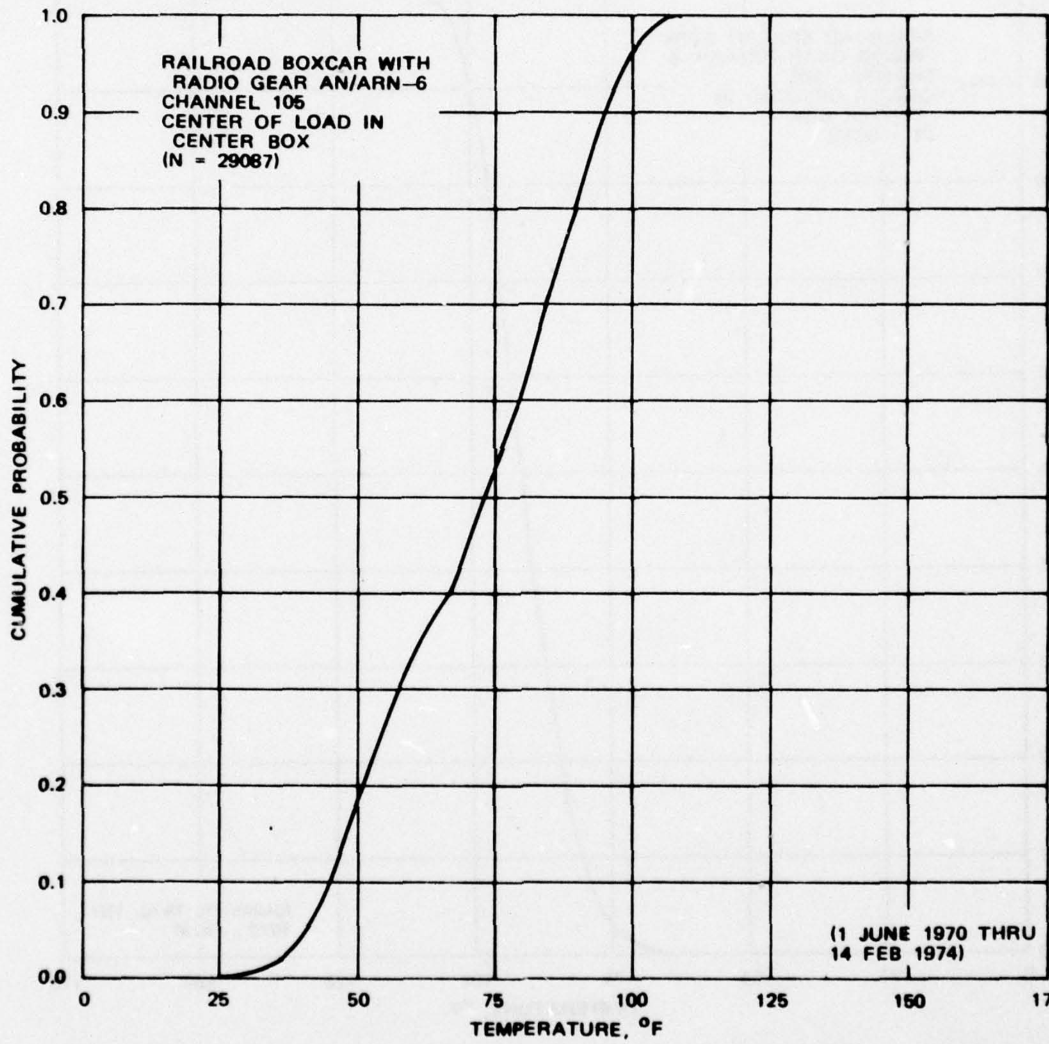

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN–6
CHANNEL 105
CENTER OF LOAD IN
CENTER BOX
(N = 29087)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 15.

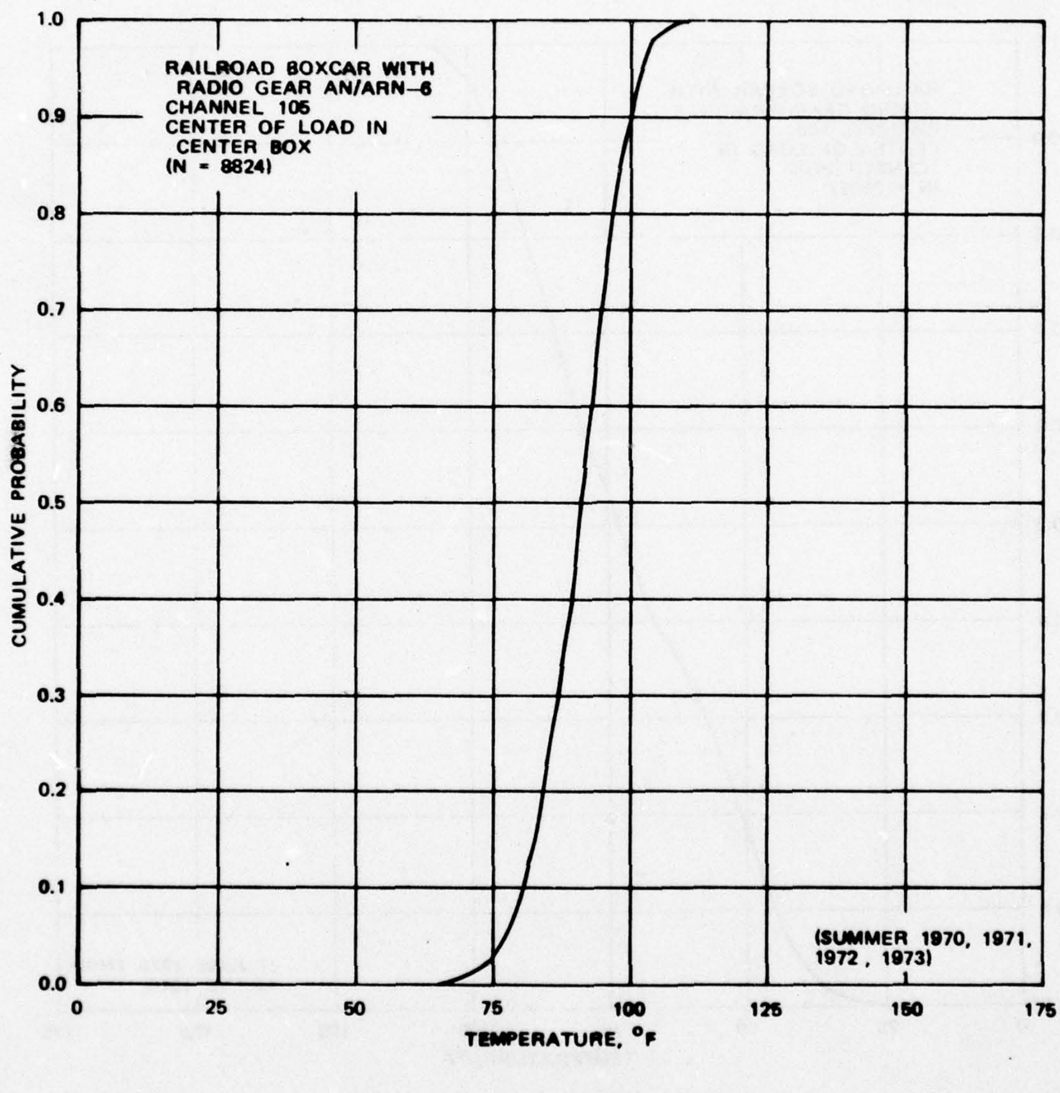

RAILROAD BOXCAR WITH
RADIO GEAR AN/ARN-6
CHANNEL 105
CENTER OF LOAD IN
CENTER BOX
(N = 8824)
(SUMMER 1970, 1971,
1972 , 1973)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 16.

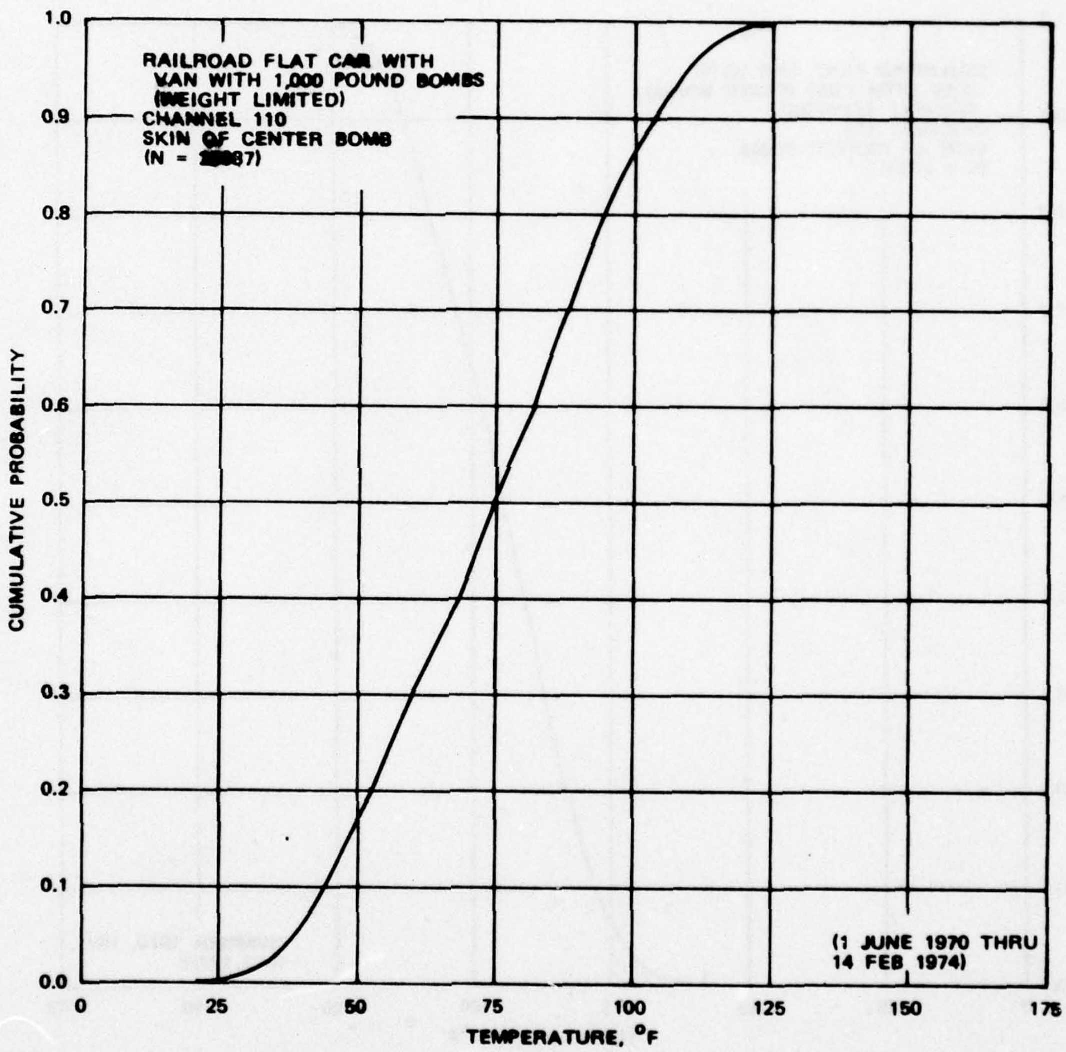

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 110
SKIN OF CENTER BOMB
(N = [redacted]7)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 17.

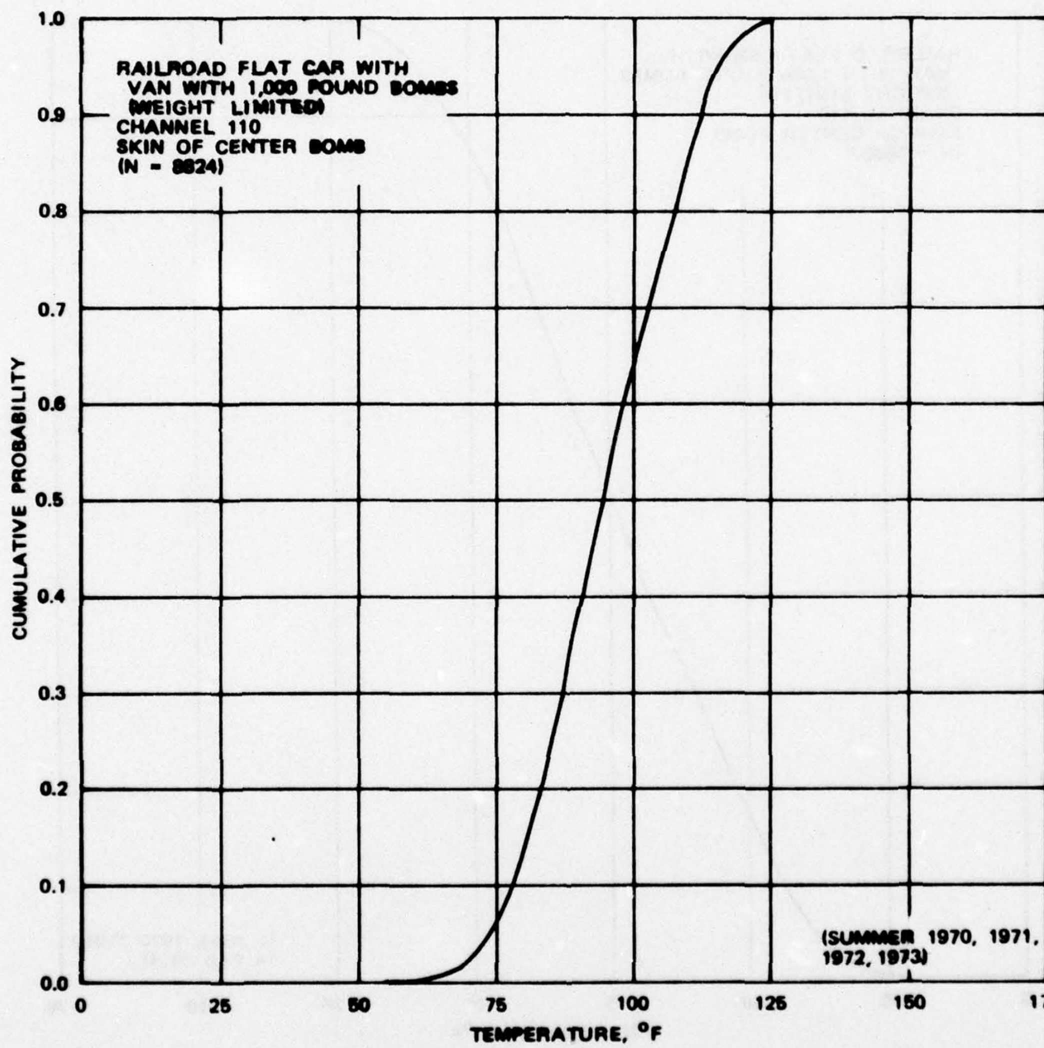

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 110
SKIN OF CENTER BOMB
(N = 8824)
(SUMMER 1970, 1971,
1972, 1973)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175

FIGURE 18.

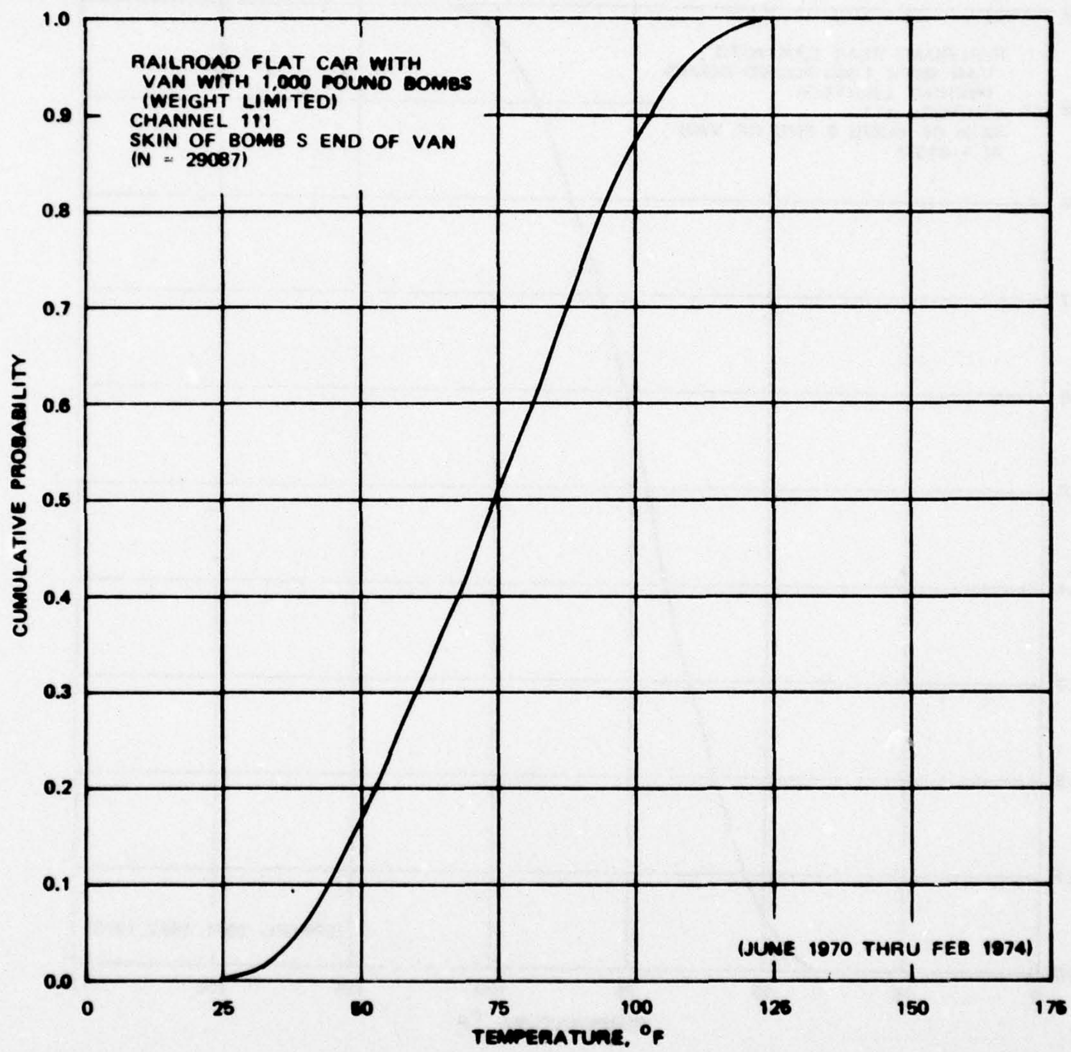

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 111
SKIN OF BOMB S END OF VAN
(N = 29087)
(JUNE 1970 THRU FEB 1974)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 19.

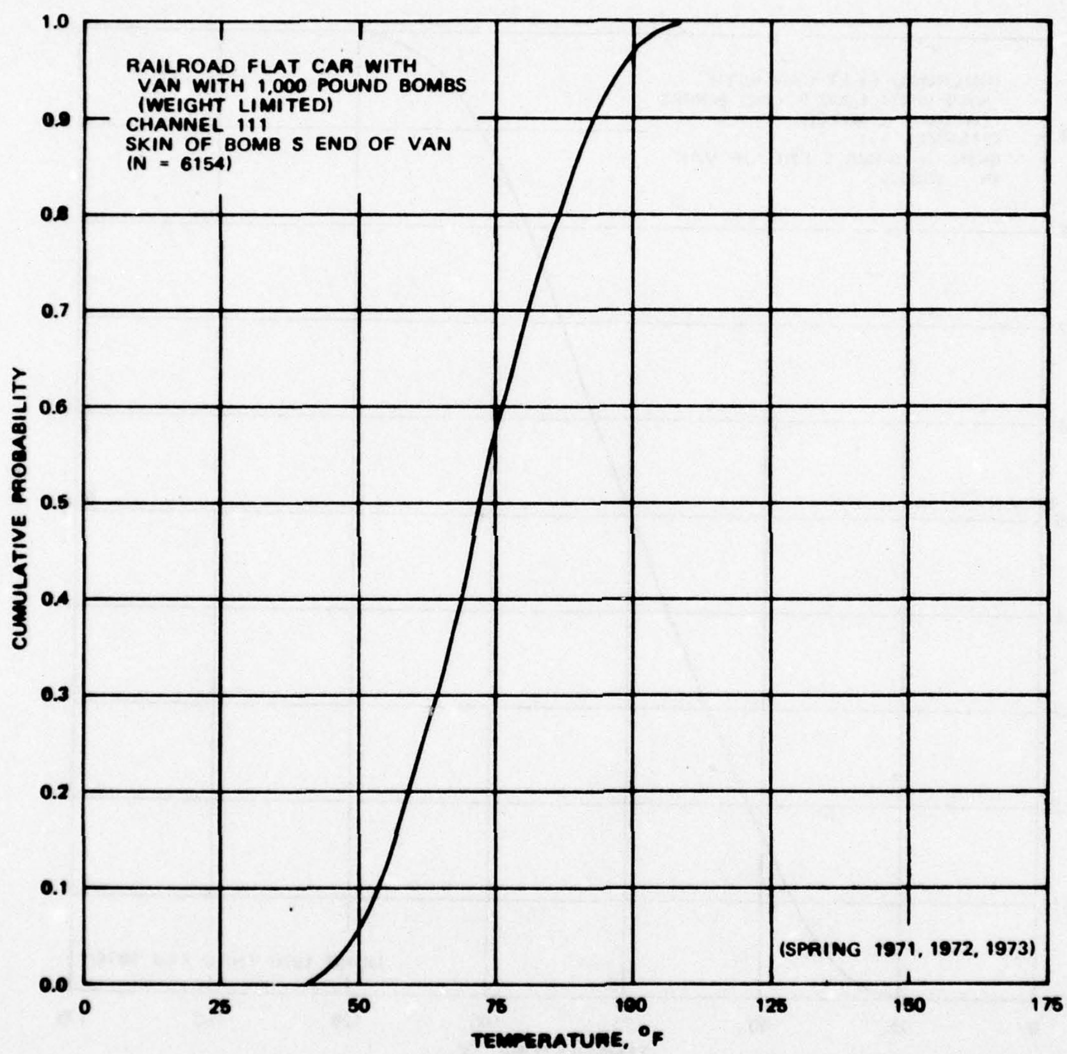

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 111
SKIN OF BOMB S END OF VAN
(N = 6154)
(SPRING 1971, 1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 20.

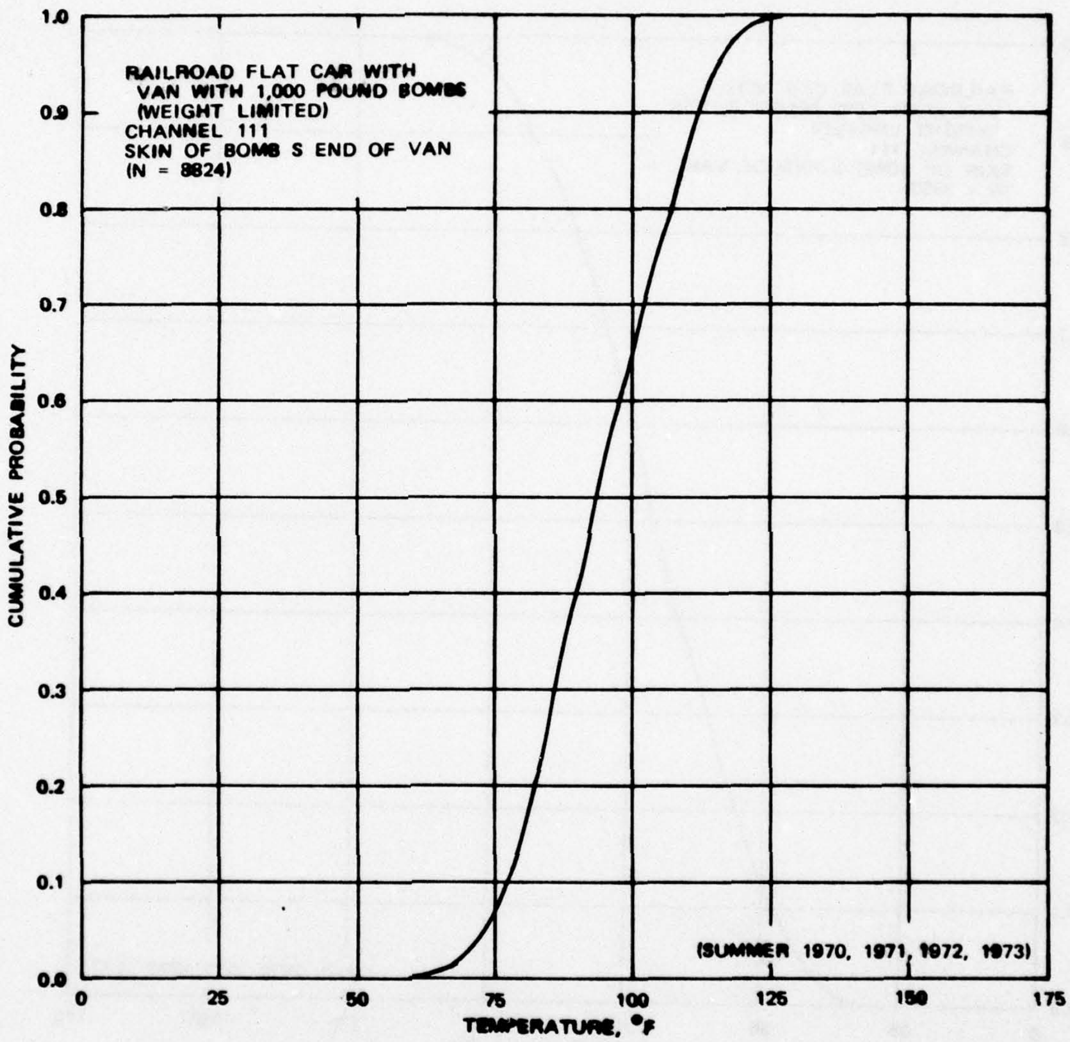
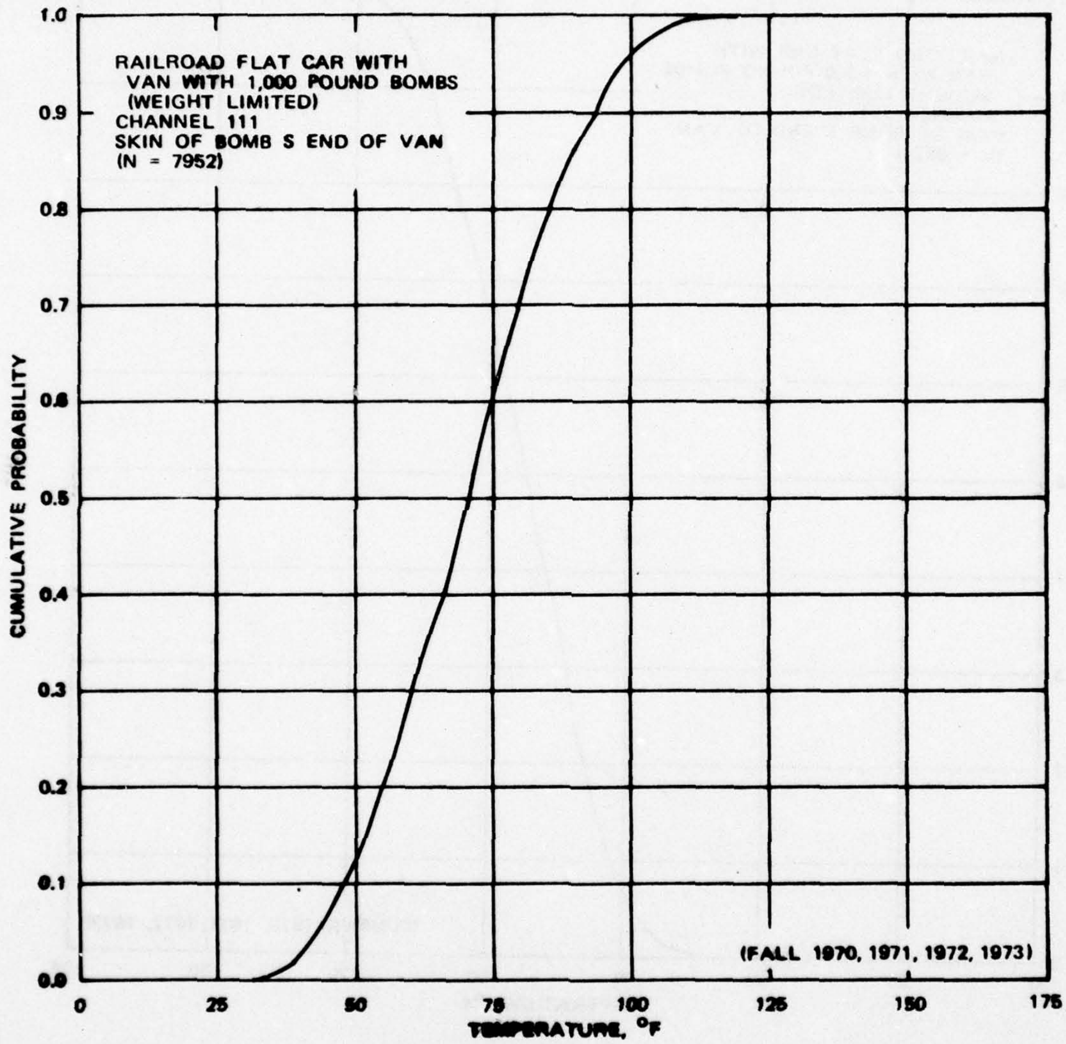
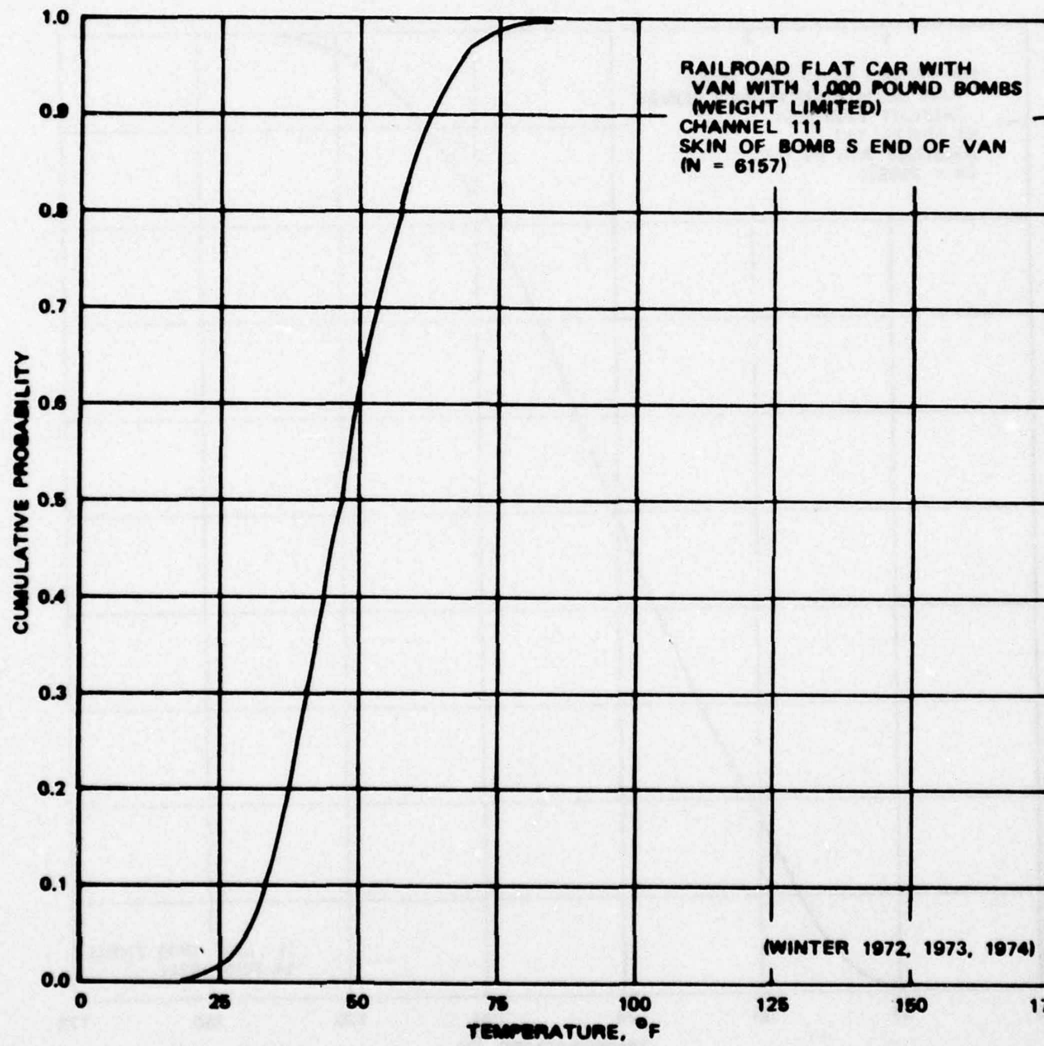

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 111
SKIN OF BOMB S END OF VAN
(N = 8824)
(SUMMER 1970, 1971, 1972, 1973)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175

FIGURE 21.



RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 111
SKIN OF BOMB S END OF VAN
(N = 7952)
(FALL 1970, 1971, 1972, 1973)
CUMULATIVE PROBABILITY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 22.



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CUMULATIVE PROBABILITY
RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 111
SKIN OF BOMB S END OF VAN
(N = 6157)
(WINTER 1972, 1973, 1974)
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 23.

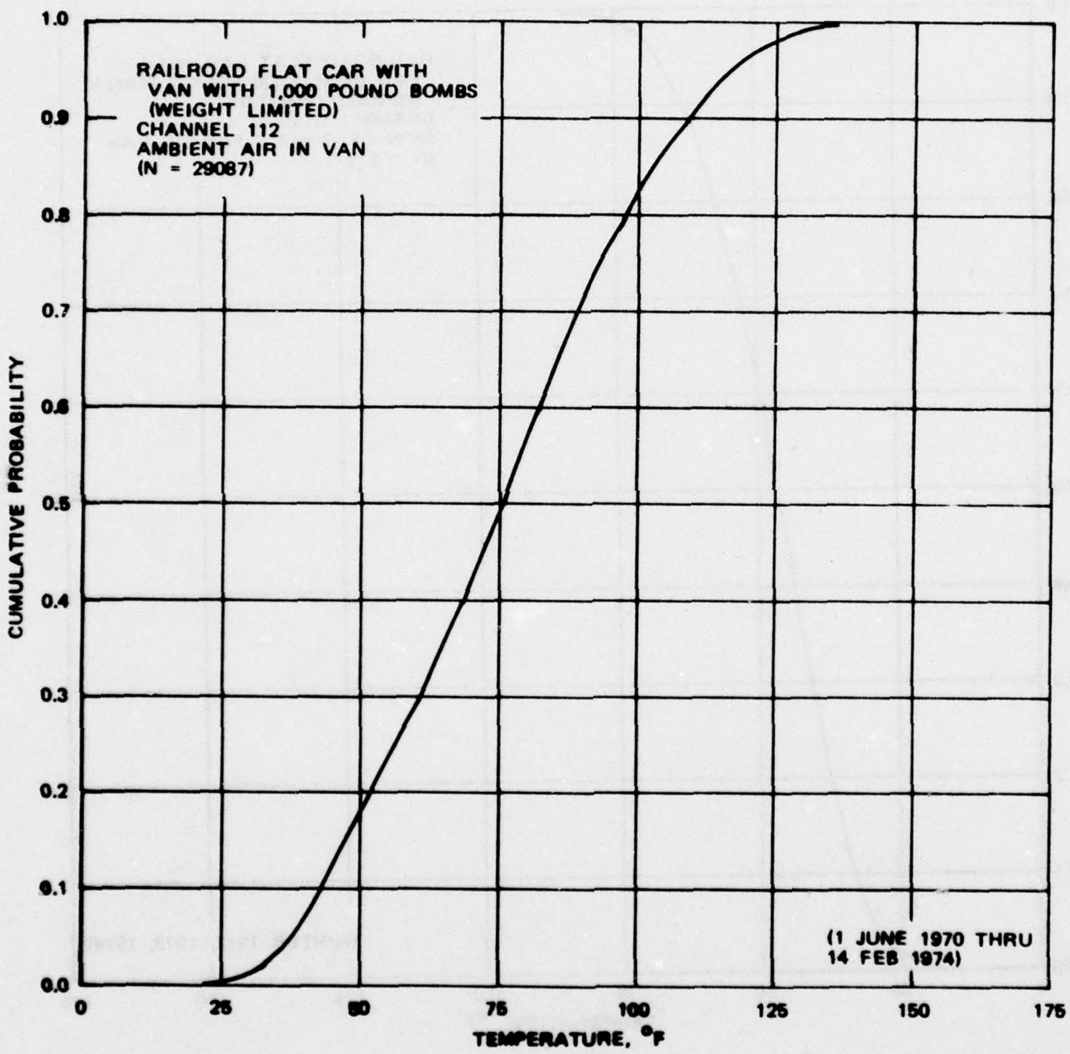

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 112
AMBIENT AIR IN VAN
(N = 29087)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 24.

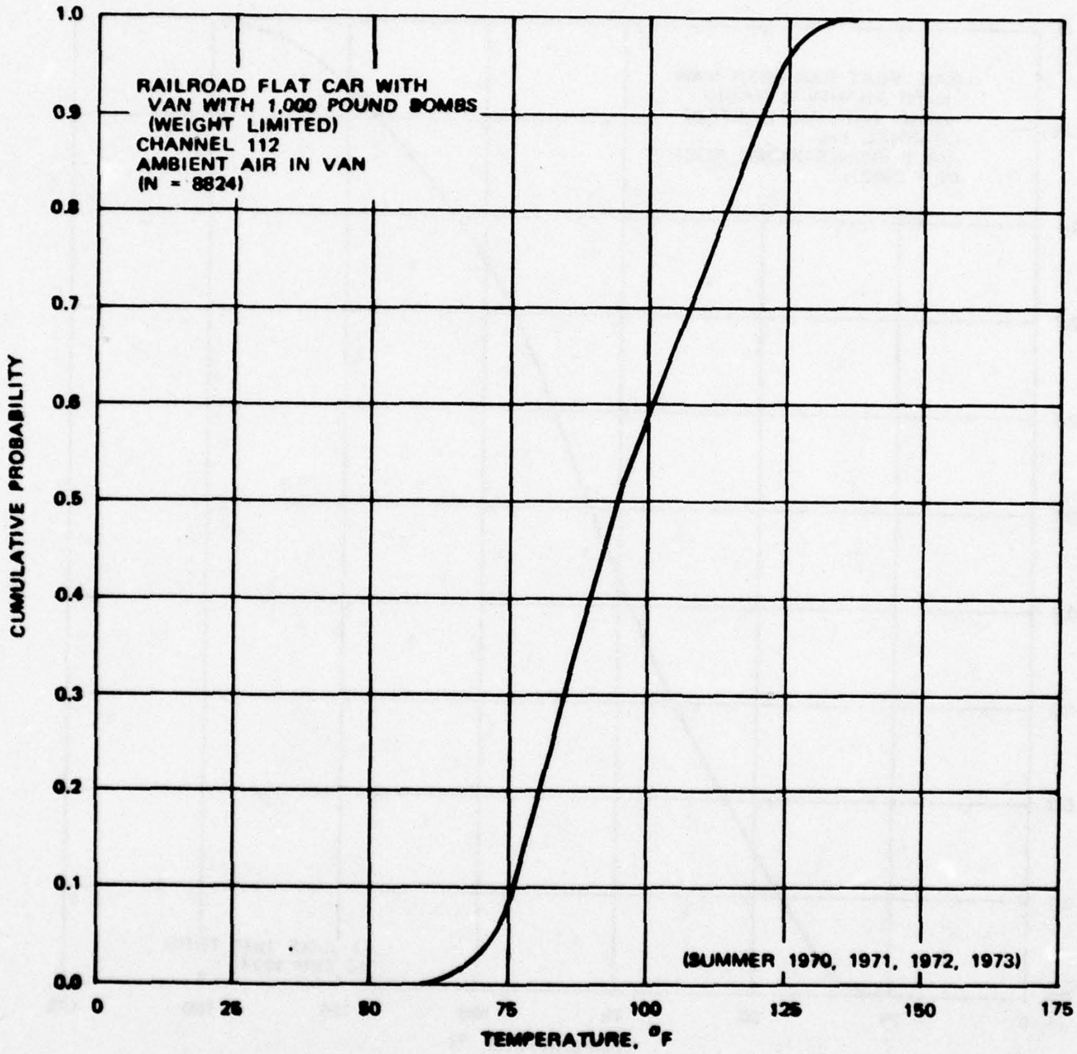

RAILROAD FLAT CAR WITH
VAN WITH 1,000 POUND BOMBS
(WEIGHT LIMITED)
CHANNEL 112
AMBIENT AIR IN VAN
(N = 8824)
(SUMMER 1970, 1971, 1972, 1973)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175

FIGURE 25.

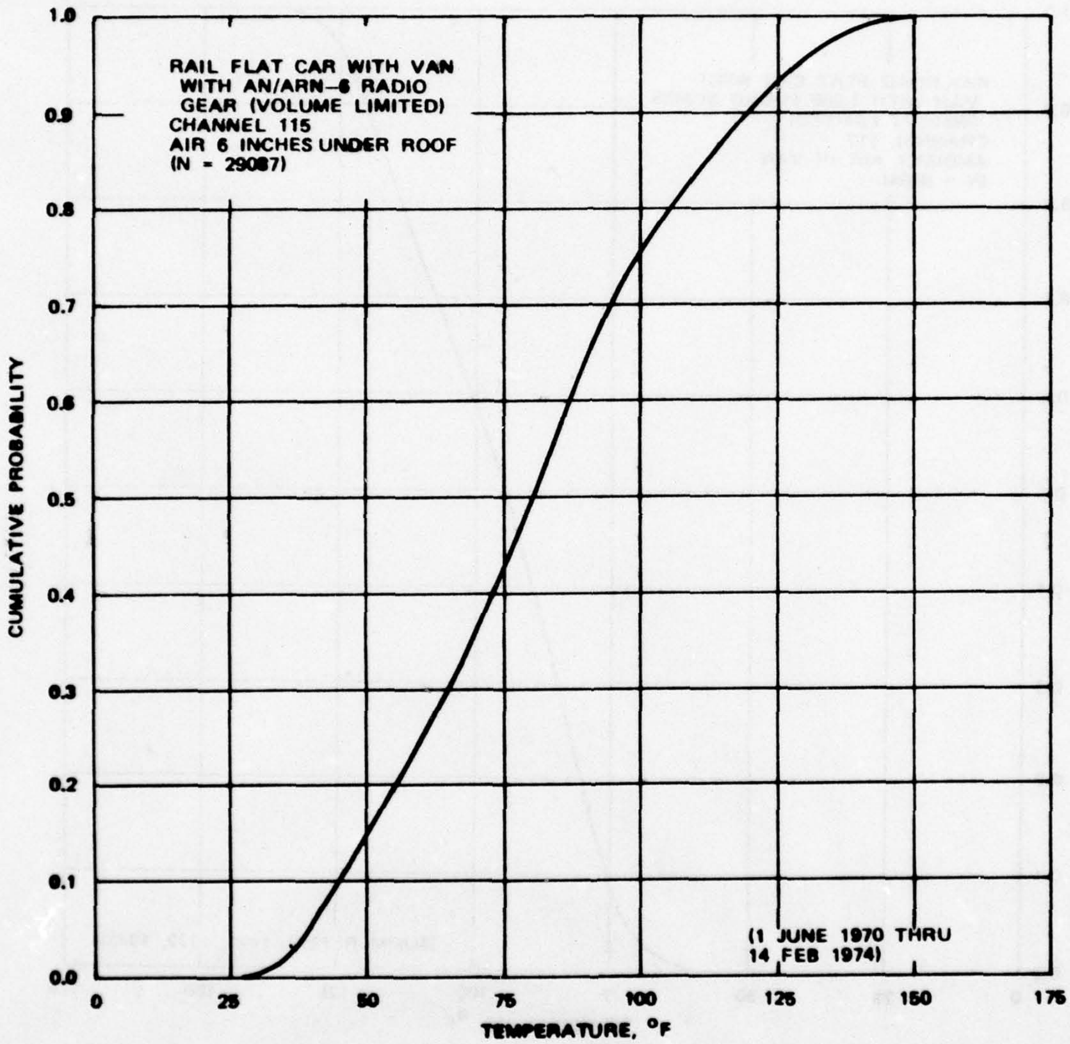

RAIL FLAT CAR WITH VAN
WITH AN/ARN–6 RADIO
GEAR (VOLUME LIMITED)
CHANNEL 115
AIR 6 INCHES UNDER ROOF
(N = 29087)
(1 JUNE 1970 THRU
14 FEB 1974)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 26.

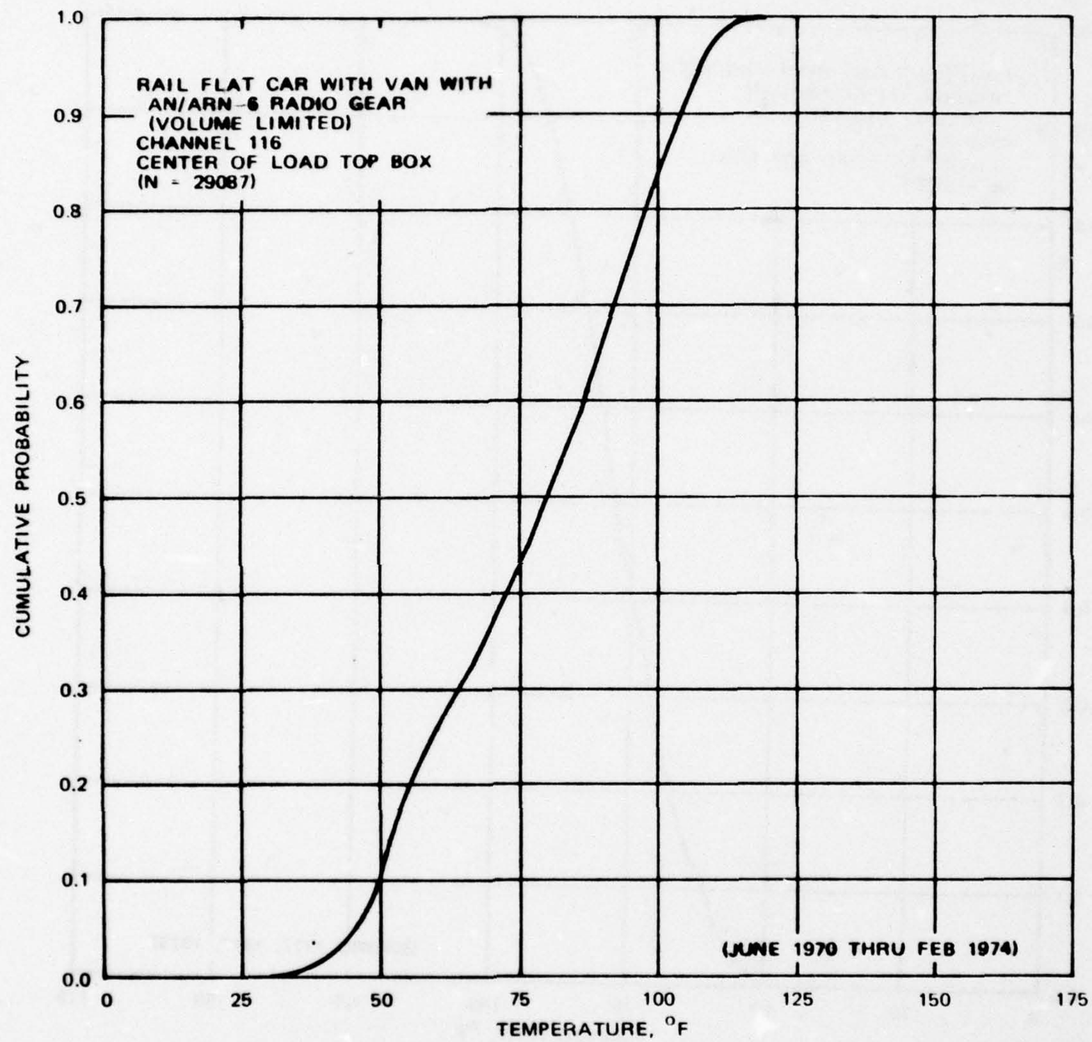
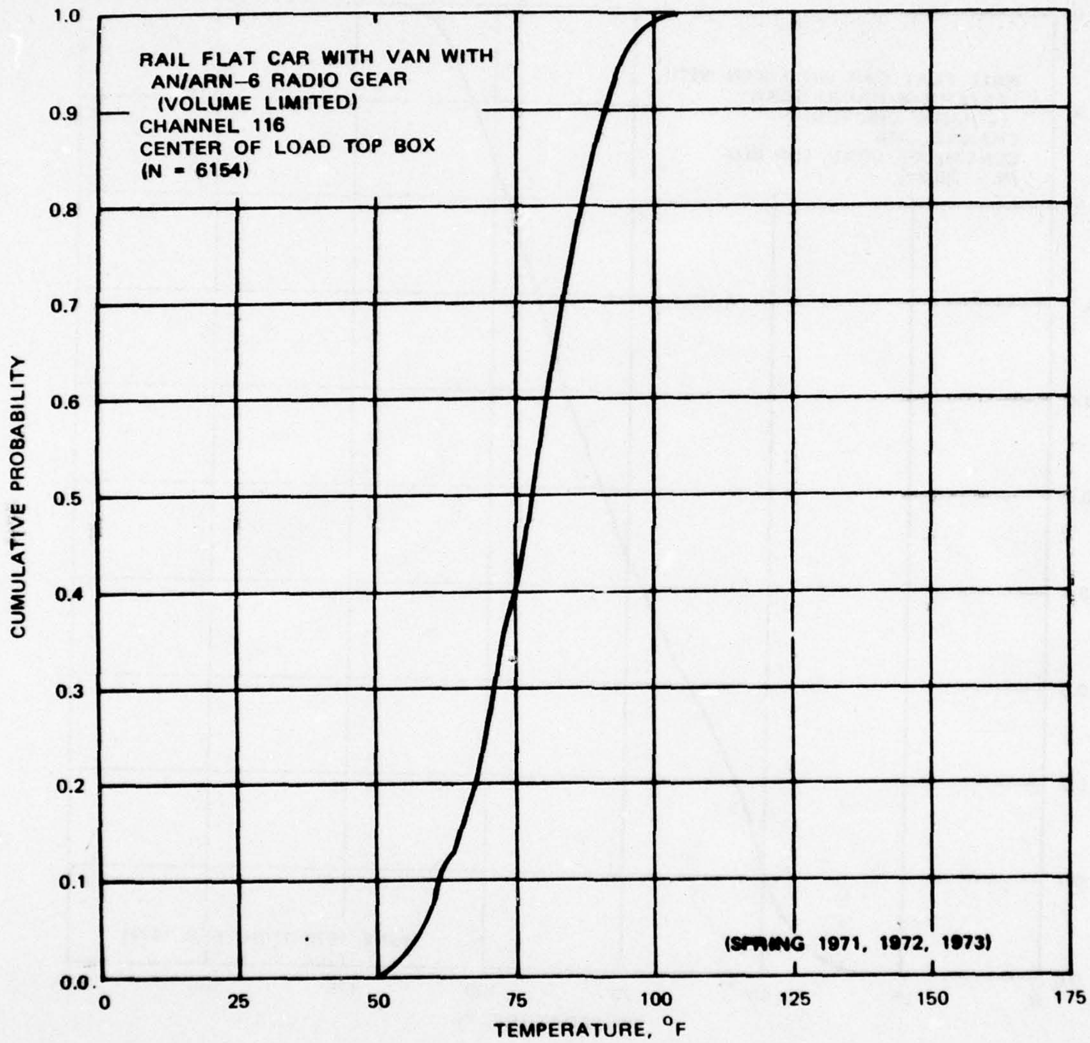

RAIL FLAT CAR WITH VAN WITH
AN/ARN-6 RADIO GEAR
(VOLUME LIMITED)
CHANNEL 116
CENTER OF LOAD TOP BOX
(N = 29087)
(JUNE 1970 THRU FEB 1974)
CUMULATIVE PROBABILITY
TEMPERATURE, °F
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175

FIGURE 27.



RAIL FLAT CAR WITH VAN WITH
AN/ARN-6 RADIO GEAR
(VOLUME LIMITED)
CHANNEL 116
CENTER OF LOAD TOP BOX
(N = 6154)
(SPRING 1971, 1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 28.

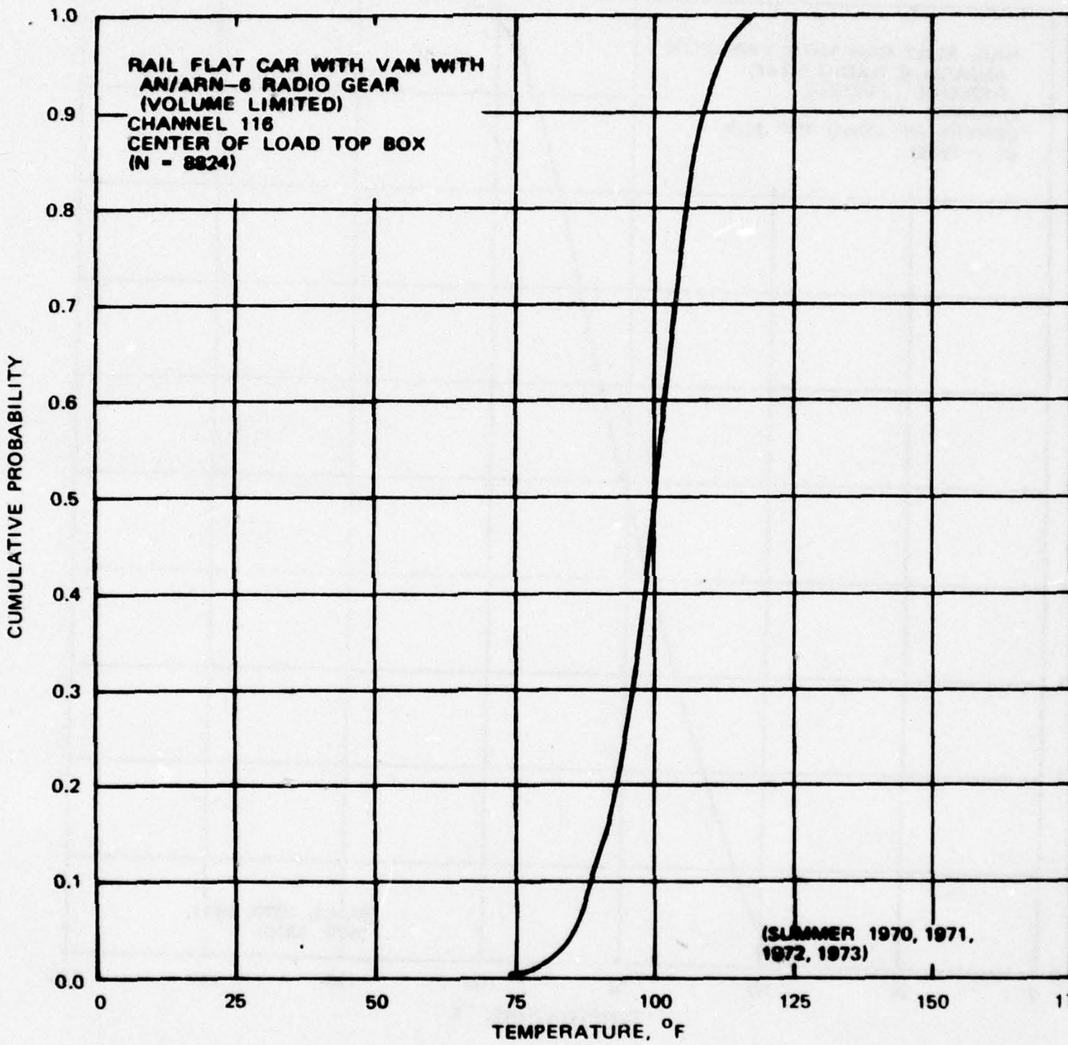
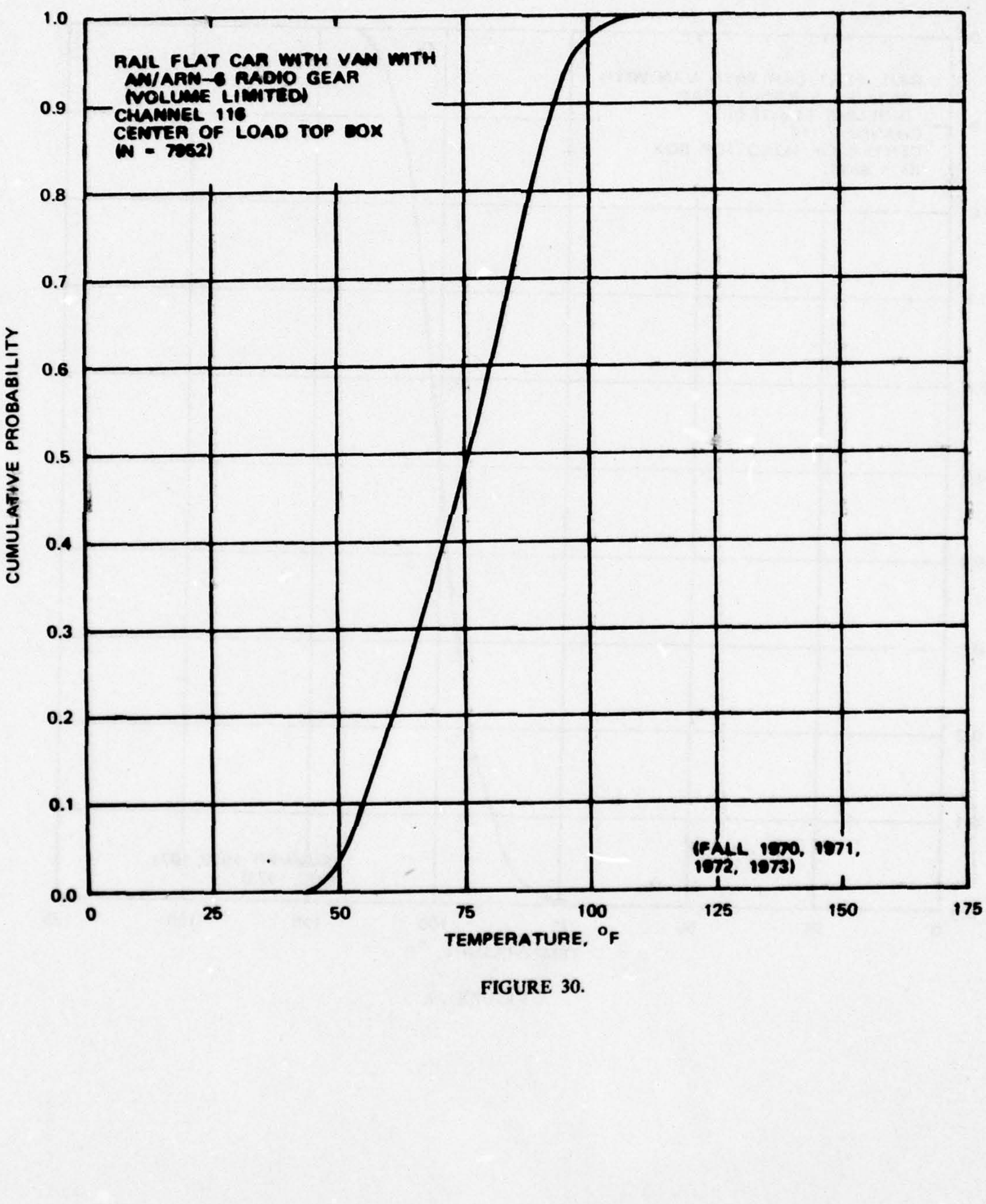

RAIL FLAT CAR WITH VAN WITH
AN/ARN-6 RADIO GEAR
(VOLUME LIMITED)
CHANNEL 116
CENTER OF LOAD TOP BOX
(N = 8824)
(SUMMER 1970, 1971,
1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 29.



RAIL FLAT CAR WITH VAN WITH
AN/ARN-6 RADIO GEAR
(VOLUME LIMITED)
CHANNEL 116
CENTER OF LOAD TOP BOX
(N = 7962)
(FALL 1970, 1971, 1972, 1973)
CUMULATIVE PROBABILITY
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 30.

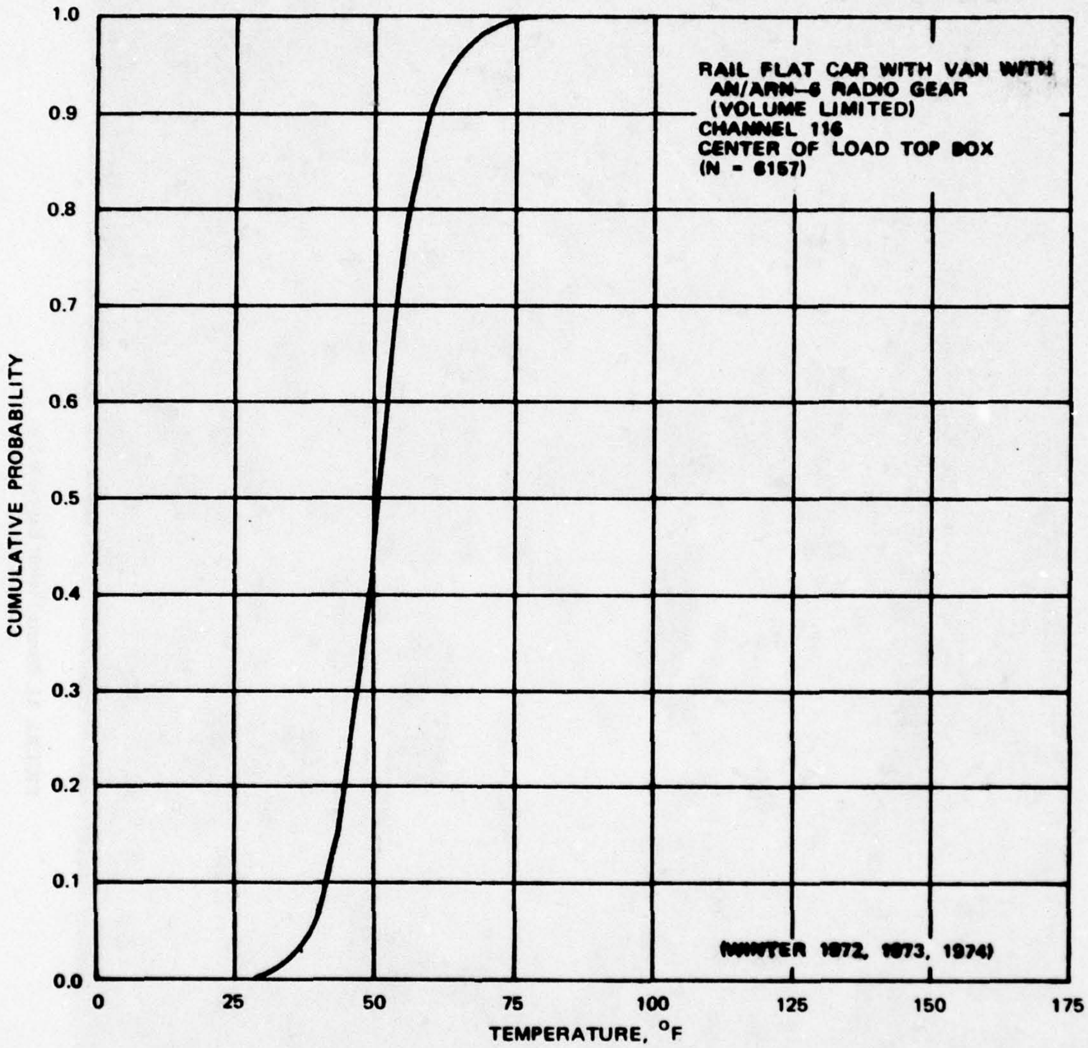

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
CUMULATIVE PROBABILITY
RAIL FLAT CAR WITH VAN WITH
AN/ARN-6 RADIO GEAR
(VOLUME LIMITED)
CHANNEL 116
CENTER OF LOAD TOP BOX
(N - 6157)
(WINTER 1972, 1973, 1974)
0
25
50
75
100
125
150
175
TEMPERATURE, °F

FIGURE 31.

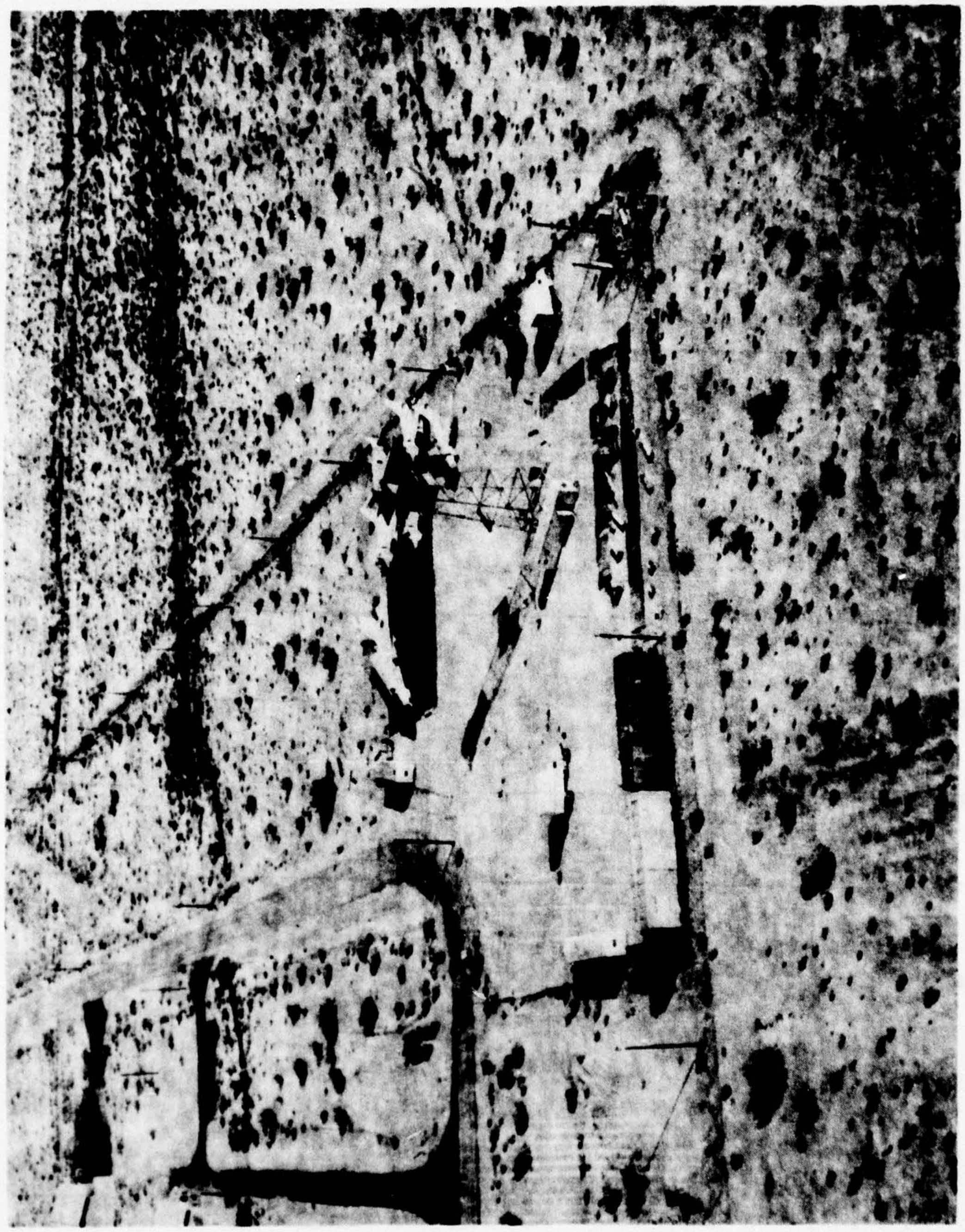


FIGURE 32. **Boxcar/Flatcar** Exposure Site.

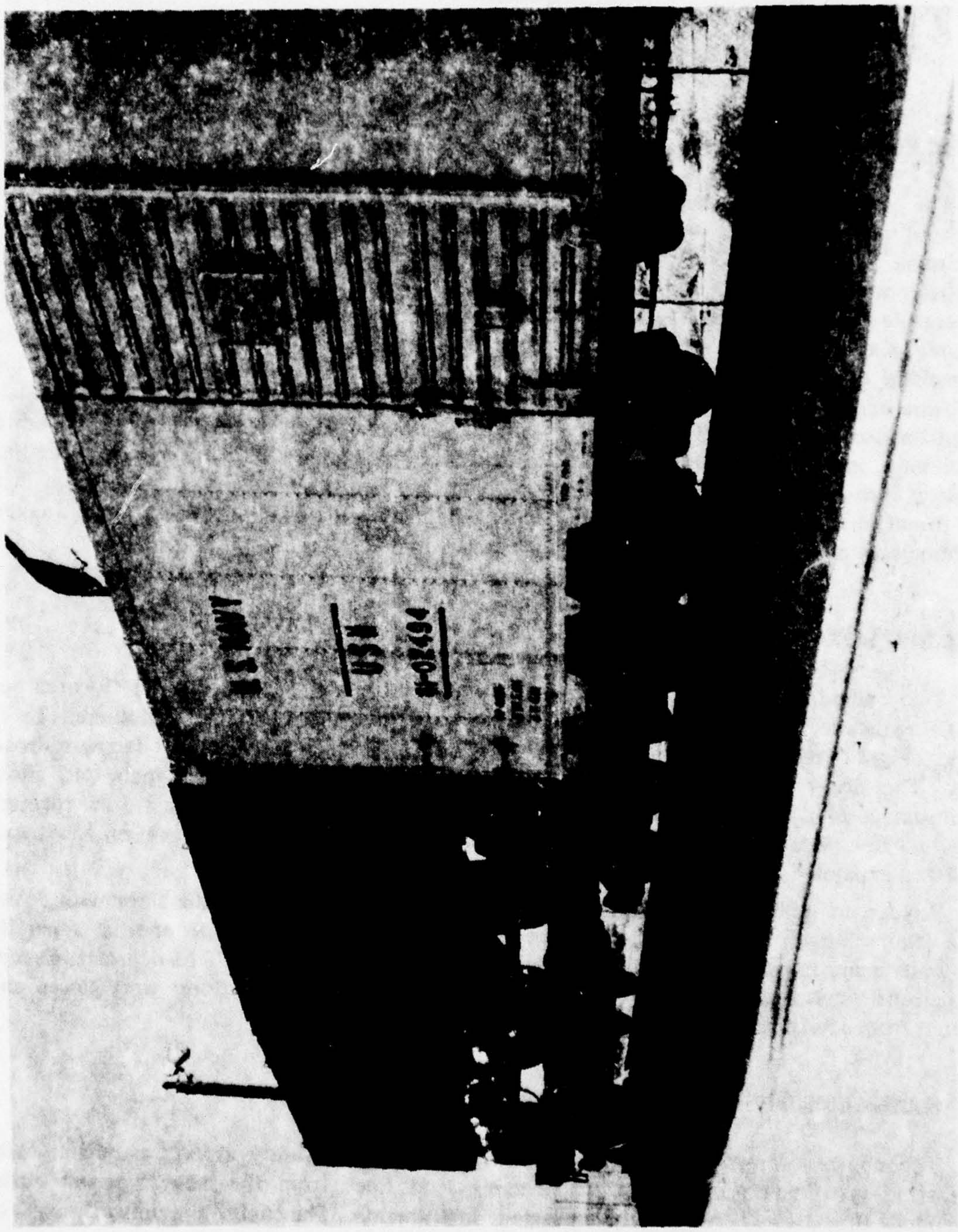


FIGURE 33. Piggyback Flatcar and Boxcar at Exposure Site.

Appendix A

NAD/HAWTHORNE MEASUREMENTS

BACKGROUND

The NAD/Hawthorne facility is located in a pure desert environment. It is situated in an elongated valley at about 4,100 feet elevation in the rain shadow of the Sierra Nevada mountains. The summers are cloudless and dry. There is no standard weather station in this specific location; however, it is safe to assume that the solar insolation is near maximum for the latitude since there is little absolute humidity and no industrial air pollutants indigenous to the area that would tend to attenuate the solar insolation. Also, there is 4,000 feet less atmosphere at Hawthorne to attenuate radiation than in either the Imperial Valley of California or the Weldon-Mohalk Valley of Arizona. The only moderators would be the small lake at the northern end of the valley that could, under some circumstances, possibly moderate the climate, and the high mountains in all quadrants that may tend to focus or reflect solar radiation into the valley. The NAD/Hawthorne facility is the only Navy depot located in a pure desert environment. All other Navy depots and stations to which in-fleet service ordnance would be sent or stored are in other than pure desert climates.

TEST BED BOXCARS

Two standard U.S. Navy boxcars (USNX28852 and USNX28170) located at NAD/Hawthorne were filled to weight capacity with precision cast trinitrotoluene (TNT) blocks (Figure A-1). The loaded boxcars were placed on a generally east-west facing railroad track. The doors of the boxcars were blocked open approximately 12 inches to allow maximum cooling of the loads. Measurements were initially conducted from 1 June through 27 July 1964. After a 16-day lapse, the measurement sequence was started again on 13 August 1964 and expanded to include an additional car with different loads.

Boxcar no. USN 61-05111 (Figure A-2) was filled to 5 feet from the floor with Army M-16 land mines in wooden boxes (Figure A-3). The car was located on another generally east-west facing railroad track about two miles from the site of the TNT loaded cars. Except for periods when recorder maintenance was carried out, the boxcar's doors were closed and secured from 13 August through 23 September 1964.

MEASUREMENT INSTRUMENTATION

The choice of instruments was extremely limited. The safety aspects associated with generating instrumentation power or stringing land lines from the nearest power outlet precluded the use of electrically operated instruments. The only remaining modes of instrumentation were maximum-minimum thermometers and clock-drive single-point pen recorders.

The TNT loaded boxcars were instrumented with only one maximum-minimum thermometer mounted 6 feet from the floor on the northern inside of the boxcar. The maximum and minimum temperatures were read and recorded each weekday. (The Monday readings, in reality, were the maximum and minimum values for Saturday, Sunday and Monday combined.)

The M-16 land mine loaded car was instrumented with single-point drag pen recorders (manufactured by Taylor Instrument Co., Rochester, N.Y., and Foxboro Co., Foxboro, Mass.). The Foxboro instruments were set to record one week's data on one circular chart. The Taylor instruments were adjusted to record only one day's data on one circular chart. This provided continuous data for a full week and more detailed daily data. In some cases data were lost because the instruments were attended only from Monday through Friday. Cross checking between records, however, indicated no loss of extreme data due to this regimen.

Placement of instruments was as follows:

1. On top of the load of M-16 land mines with the measuring element 6 feet above the floor. The recorder was 20 feet from the end of the boxcar (Taylor Instrument–daily).
2. Resting on the deck in the center of the car, between the doors (Taylor–daily).
3. Six inches beneath the roof on the south side of the boxcar, 4 feet back from the door (Foxboro–weekly).
4. Six feet from the deck of the boxcar, 4 feet back from the door on the northern side of the boxcar. This placement duplicates exactly the placement of the maximum-minimum thermometer in the TNT portion of the test (Foxboro–weekly).

Since separate instruments were employed at each of the above points, an accurate comparison of time-of-maximum-temperature phase was not strictly possible. An error of only a fraction of an inch in the placement of the circular chart in the instrument could mean hours of error on the pre-marked charts. A fair idea could, however, be obtained as to the phase relationship between the four points of measurement.

RESULTS

Since only minimum-maximum temperatures were obtained from the TNT loaded boxcars and more complete data were collected from the M-16 land mine loaded boxcar, the results of these measurements are, in part, a reconstruction.

Table A-1 shows maximum and minimum thermometer readings for the TNT loaded boxcars from 1 June through 27 July 1964. Maximum temperatures recorded for the M-16 land mine loaded car from 13 August through 23 September 1964 are given in Table A-2. As can be seen, some method, even though approximate, must be developed to make the higher temperatures reported in Table A-1 relevant.

Figure A-4 plots the temperature readings obtained for the most extreme day for which data were available. The curve numbers correspond to the previously listed instrumentation locations. The following correlation was derived based on this figure and substantiated using for other days in the measurement series.

TABLE A-1. Temperature Maximum and Minimum Values Recorded in Navy Ammunition Boxcars USNX28852 and USNX28170, and Ambient Air at NAD/Hawthorne During Summer 1964. (All temperatures in degrees Fahrenheit.)

Date	Outside Air			Boxcar USNX28852			Boxcar USNX28170		
	Max.	Min.	Variation	Max.	Min.	Variation	Max.	Min.	Variation
June									
1	83	46	37	96	44	52	100	50	50
2	83	53	30	100	50	50	102	54	48
3	81	50	31	96	48	48	100	54	46
4	85	62	33	100	66	44	96	64	32
5	78	55	23	96	40	56	98	54	44
8	81	46	35	100	38	62	96	42	54
9	59	42	17	...	...	...	...	...	...
10	64	40	14	80	36	44	84	44	40
11	70	45	25	84	40	44	88	48	40
12	73	45	28	94	46	48	96	42	54
15	90	54	36	100	50	50	104	56	48
16	75	48	27	74	44	34	78	50	38
17	71	50	21	...	...	...	...	...	...
18	75	46	29	100	40	60	94	42	52
19	78	51	27	98	44	54	92	50	42
22	85	46	39	96	44	52	100	50	50
23	84	53	31	100	44	56	104	54	50
24	92	58	34	108	54	54	110	60	50
25	100	61	39	108	56	52	112	62	50
26	100	68	32	112	...	...	114	...	...
29	95	53	42	...	...	...	...	...	...
30	89	54	35	106	50	56	106	58	48
July									
1	91	55	36	...	...	...	...	...	...
2	91	58	33	106	52	54	108	58	50
6	92	52	30	104	48	56	106	54	52
7	94	60	34	108	56	52	112	60	52
8	102	60	42	110	56	54	114	64	50
9	96	55	41	110	52	58	114	60	54
10	92	59	33	106	58	48	108	64	44
13	101	60	41	112	56	56	116	64	52
14	100	67	33	106	60	46	110	66	44
15	95	55	40	108	54	54	110	60	50
16	94	59	35	106	56	50	110	62	48
17	96	65	31	108	60	48	110	64	46
20	100	59	41	114	56	58	116	62	54
21	100	59	41	114	58	56	116	64	52
22	96	59	37	110	56	54	112	62	50
23	96	60	36	...	...	...	...	...	...
24	96	61	35	...	...	...	...	...	...
27	100	65	35	...	...	...	...	...	...
28	98	63	35	...	...	...	...	...	...
29	93	62	31	...	...	...	...	...	...
30	98	68	30	...	...	...	...	...	...
31	97	58	39	118	54	64	120	60	60

TABLE A-2. Maximum Temperatures M-16 Land Mine Loaded Boxcar Series, NAD/Hawthorne, 1964. (All temperatures in degrees Fahrenheit.)

Date	Recorder				
	5	2	3	1	4
	On deck, center of car. Doors blocked open 12"	On deck center of car	6" from roof, 4' back from door	5' to 7' from deck, 20' from end of car	6' from deck, 4' back from door
Aug					
13	98	99	118	107	...
14	94	95	112	...	...
15	87	96	113	...	102
16	87	98	115	...	103
17	101	102	118	112	108
18	96	97	108	104	100
19	81	85	95	89	85
20	84	88	100	94	90
21	88	90	106	98	94
22	94	95	112	105	100
23	97	99	116	...	104
24	96	99	114	106	...
25	96	100	116	108	...
26	99	95	108	100	...
27	93	89	104	97	92
28	96	90	106	98	92
29	86	81	94	82	83
30	94	88	105	97	92
31	73	70	73	73	70
Sep					
1	75	69	84	76	72
2	81	77	98	...	84
3	88	82	100	91	87
4	94	87	108	99	95
5	94	87	106	97	94
6	89	...	95	...	86
7	92	...	102	...	91
8	94	88	107	99	95
9	90	84	102	93	90
10	91	85	100	92	88
11	94	88	105	97	94
12	95	89	108	100	96
13	95	89	104	97	94
14	90	86	99	92	88
15	89	83	98	90	87
16	96	89	109	101	97
17	...	85	97	92	90
18	...	78	90	85	82
19	...	79	98	90	85
20	...	83	104	95	90
21	...	72	86	78	76
22	...	76	93	85	80
23	...	81	94	88	84

Correlation

If the air temperature at the wall of a boxcar is known, the air temperature above the load in the center of a closed boxcar can be approximated. Since the sidewall temperature obtained in this measurement series was always on the northeastern ("cold") wall, it is evident that the interior of the boxcar may have seen a warmer air temperature. Because the least amount of insulation exists between the sidewall thermometer and the outside condition, the thermometer is more responsive to outside conditions. As can be seen from Figure A-4, curve 4 shows a response to the sun in the morning and to the shade in the afternoon. Curves 4 and 3, representing the air near the side and roof, respectively, of the boxcar cool off more rapidly than does the load (curve 1). The relationship between the temperature levels at these three sites is as follows: Obtain the minimum temperature inside the boxcar for the beginning of the temperature onset. (In the 17 August case, 65°F was used.) Subtract from the peak value for each temperature parameter the base temperature, and convert to percent.

For example;

17 August 1964: No. 1 - 112°F - 65°F = 47°F ΔT
No. 2 - 102°F - 65°F = 37°F ΔT
No. 3 - 118°F - 65°F = 53°F ΔT
No. 4 - 108°F - 65°F = 43°F ΔT

% change in No. 1 as compared to No. 4

$$\frac{47 - 43}{47} \times 100 \approx 8\%$$

% change in No. 3 as compared to No. 4

$$\frac{53 - 43}{53} \times 100 \approx 19\%$$

A rapid check through the data indicates that this is a fair indication of the factor to be used on the TNT boxcar data to arrive at the inside air temperature when only the wall temperature is known. A comparison was made against the data from one month later.

16 Sep 1964: No. 1 - 101°F – 55°F = 46°F ΔT
No. 3 - 109°F – 55°F = 54°F ΔT
No. 4 - 97°F – 55°F = 42°F ΔT

% change in No. 1 as compared to No. 4

$$\frac{46 - 42}{46} \times 100 \approx 9\%$$

% change in No. 3 as compared to No. 4

$$\frac{54 - 42}{54} \times 100 \approx 22\%$$

By applying factors to the data from the TNT portion of the measurement series (using the above factors of about 9% for inside air temperature above the ordnance load and about 20% for the air temperature 6" under the roof of the boxcar) we will have a calculated estimate of the maximum thermodynamic driving force present and to which the TNT was exposed. It must be emphatically stated that these temperatures are only air temperatures and, in the case of massive ordnance or rocket motors, cannot be more than the skin temperature. The maximum internal ordnance temperature will always be lower than the skin in a maximum temperature boxcar regime.

The most extreme temperature, seen in Table A-1, was 120°F in boxcar USNX28170 on some day between 23 and 31 July 1964. If the equivalent temperature of No. 4 is 120°F then:

No. 1 - $120°F \times 1.09 = 131°F$

This would be the maximum peak thermodynamic driving force present and acting on the TNT.

No. 3 - $120°F \times 1.20 = 144°F$

This would be the calculated maximum temperature 6 inches under the roof of the boxcar. This value is presented here only to provide subsequent environmental investigators with a first approximation method for comparing work done by the Natick Laboratory on dark colored boxcars with current and subsequent work done on aluminum colored boxcars. This value is in no way to be construed as a maximum ordnance temperature. The ordnance temperature will always be lower.

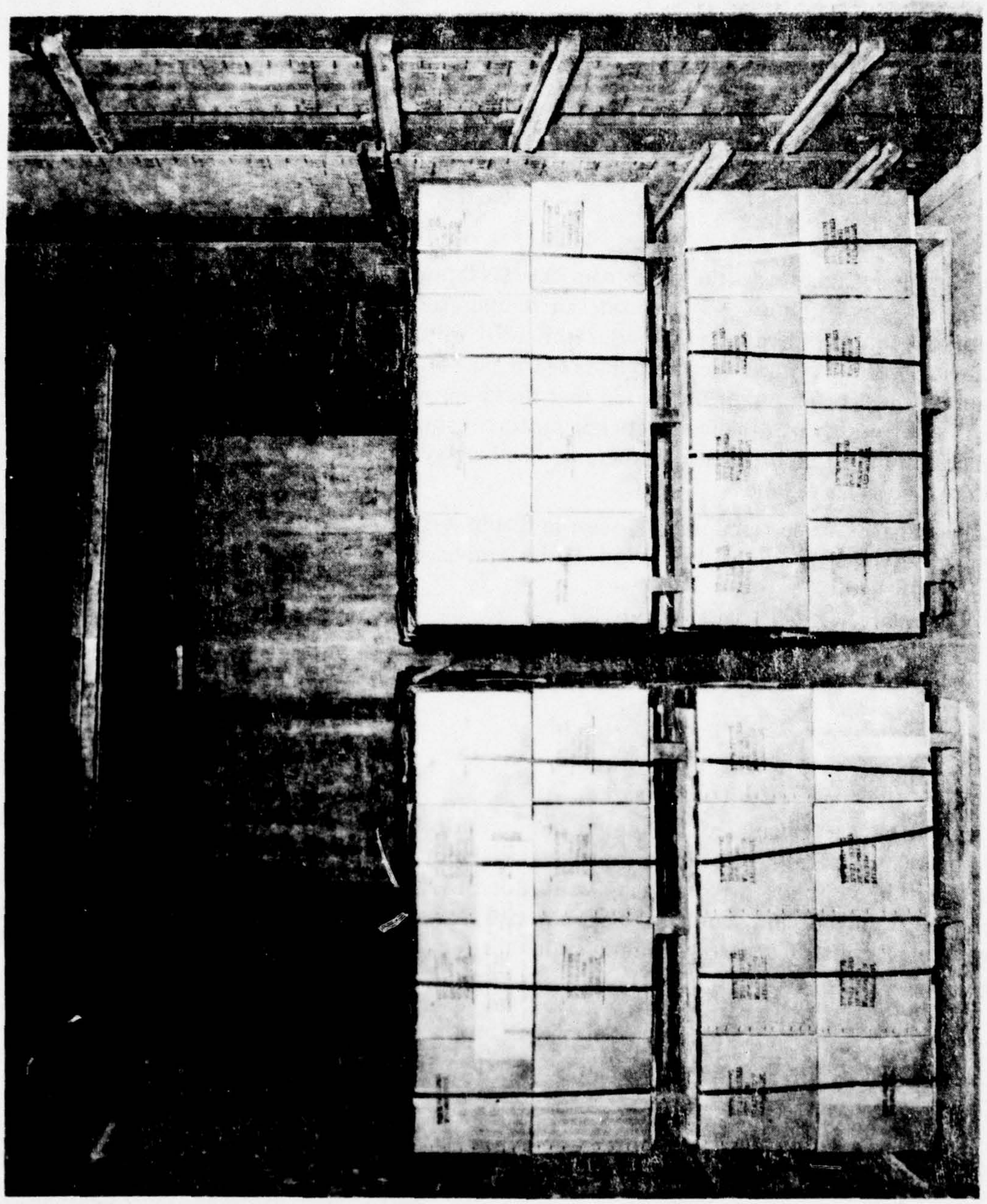


FIGURE A-1. Weight-Limited Load (TNT Blocks).

FIGURE A-2. NAD/Hawthorne Boxcar Test Bed.

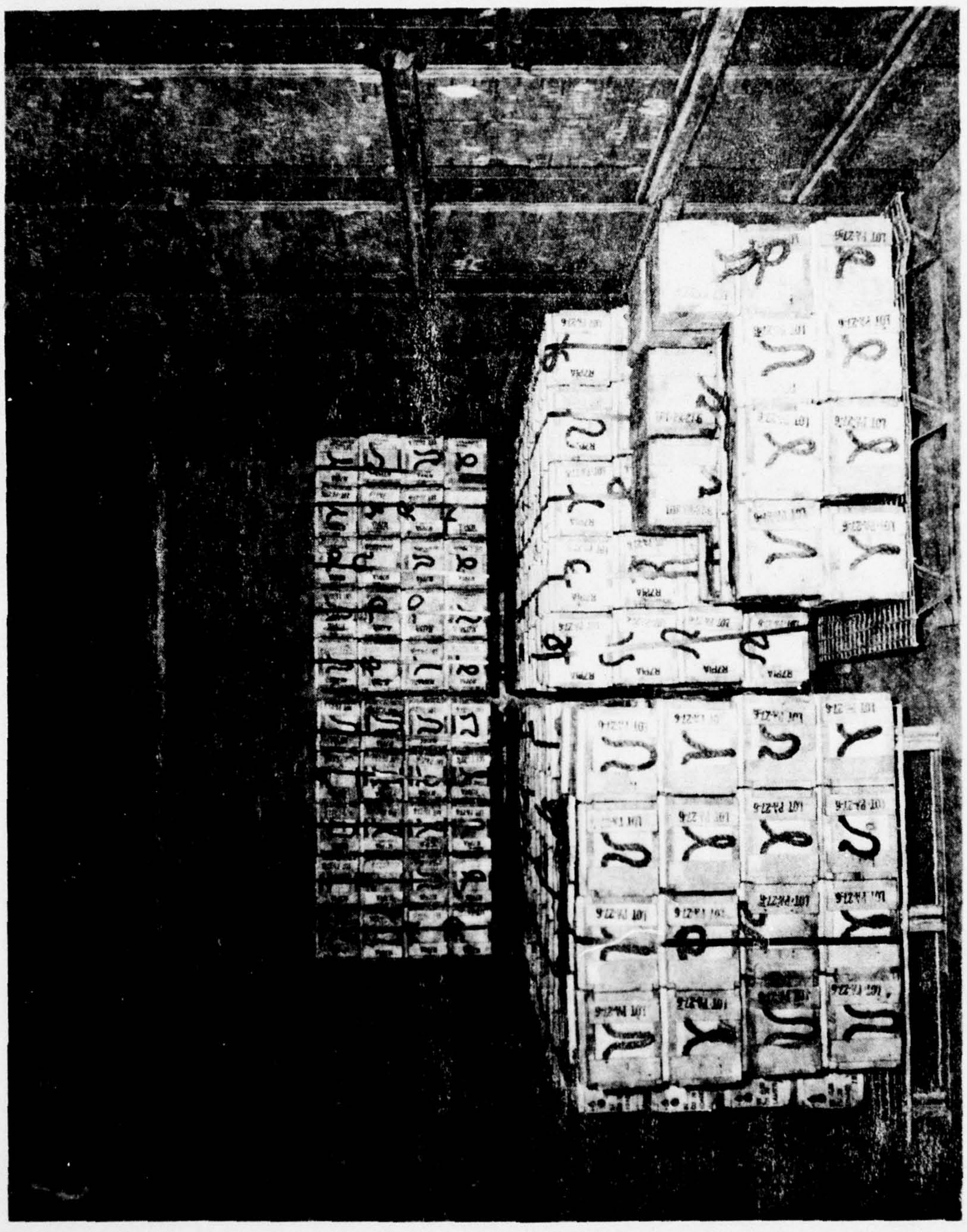


FIGURE A-3. Boxcar Loaded With Army M-16 Land Mines.

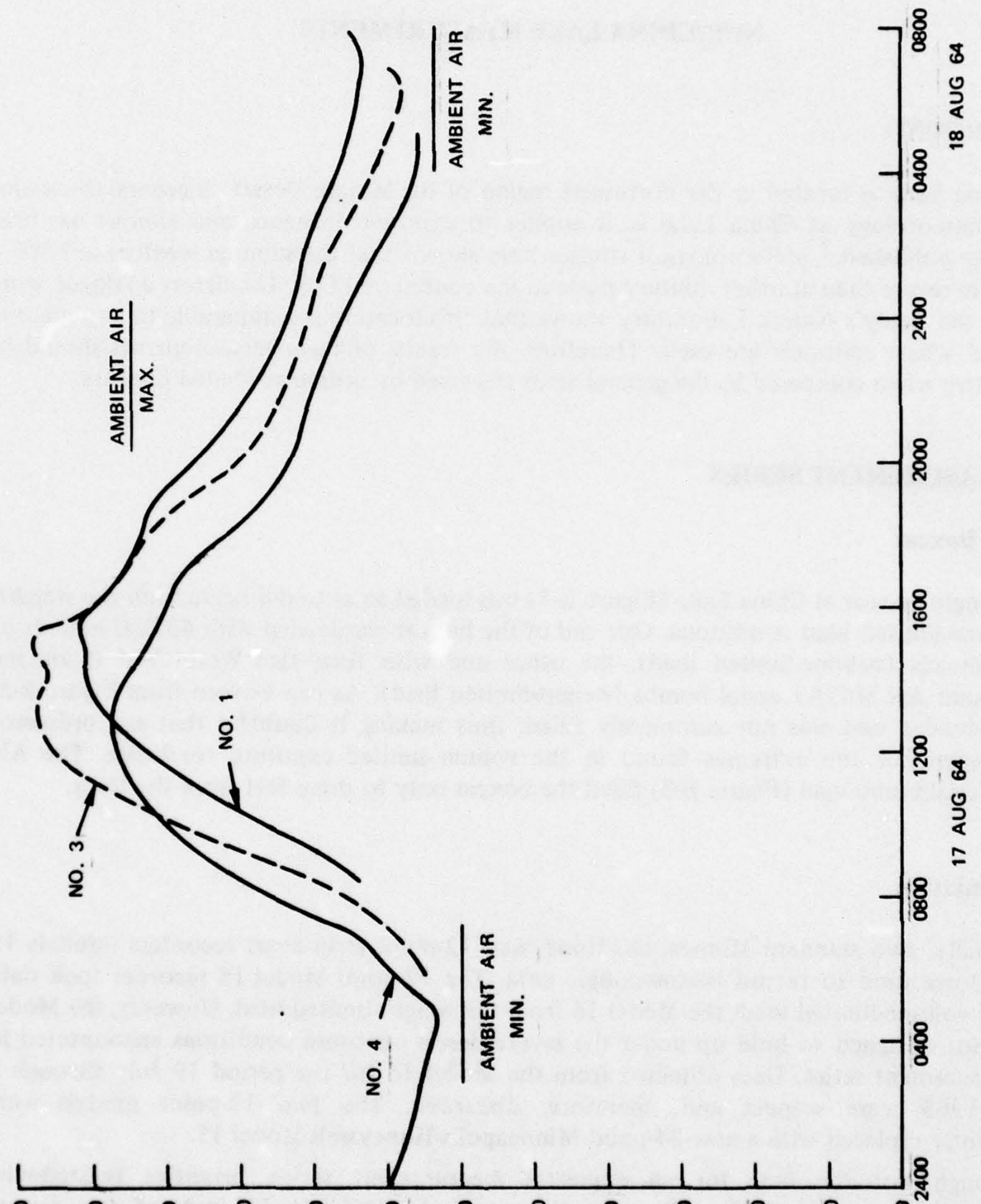


FIGURE A-4. Temperature Readings for Most Extreme Day.

Appendix B

NWC/CHINA LAKE MEASUREMENTS

BACKGROUND

China Lake is located in the northwest region of the Mojave Desert. A general discussion on the meteorology at China Lake as it applies to exposed ordnance and aircraft has been previously published.[2] Meteorological studies have shown that the summer weather at NWC is as or more severe than at other military posts in the continental U.S. The desert analogue work done by the Army's Natick Laboratory shows that this location is comparable to any place in the world where railroads are used. Therefore, the results of these measurements should be conservative when compared to the general areas traversed by ordnance-loaded boxcars.

1965 MEASUREMENT SERIES

Test Bed Boxcar

A single boxcar at China Lake (Figure B-1) was loaded so as to duplicate both the weight- and volume-limited load conditions. One end of the boxcar was loaded with 43,000 pounds of Zuni warheads (volume-limited load), the other end with forty-two World War II vintage 1,000-pound AN M65A1 aerial bombs (weight-limited load). As can be seen from Figure B-2, the Zuni-loaded end was not completely filled; thus making it doubtful that any ordnance would experience the extremes found in the volume-limited exposure condition. The AN M65A1 aerial bomb load (Figure B-3) filled the boxcar only to three feet from the floor.

Instrumentation

Initially, two standard Minneapolis-Honeywell 12-point strip chart recorders (Models 15 and 16) were used to record thermocouple data. The 12-point Model 15 recorder took data from the volume-limited load; the Model 16 from the weight-limited load. However, the Model 16 was not designed to hold up under the severe desert exposure conditions encountered in this measurement series. Data obtained from the Model 16 for the period 19 July through 2 August 1965 were suspect and, therefore, discarded. The two 12-point models were subsequently replaced with a new 24-point Minneapolis-Honeywell Model 15.

Though not the best for an exposure measurement series, primitive twisted-wire thermocouples were used. In this type thermocouple, the last 1/4 inch of the copper constantan wires are twisted and soldered together. It is difficult to install these thermocouples on a curved surface such as a Zuni rocket or bomb. There is some doubt as to whether the junction is measuring the ordnance temperature since the hot junction (last twist toward the instrument) could, in actuality, be in the air. Under such a condition, the measured temperature is between that of the air and the ordnance surface.

[2] Naval Weapons Center. *Exposure Temperatures of Damp Stored Ordnance. Part 1. Discussion and Results*, by H.C. Schafer. China Lake, California, NWC, November 1972.(NWC TP 5039, Part 1, publication UNCLASSIFIED.)

Results

Because the boxcar did double duty (containing both weight- and volume-limited loads), there is some possibility of error in the temperature measurements. The extremely hot air above the weight-limited load could have flowed across to the volume-limited load, replacing cooler air at the same strata. However, the amount of energy transferred is assumed to be small under the thermo syphon condition. Evidence indicated that there was less difference than anticipated between the air temperature above the bombs and the ordnance temperature at the top of the volume-limited load.

The maximum temperatures recorded are shown in Figure B-4. As can be seen, 113°F was the maximum temperature experienced by any of the ordnance in the boxcar, and this was only for the top layer of the volume-limited load. Figure B-4 also shows that it took a full week of thermal buildup to produce the conditions inside the boxcar which resulted in this temperature value. The start of a similar situation is evident during the period from 31 July through 5 August 1965. Had the 2nd of August been a formidable day, a maximum situation could have occurred. It is noted that the 113°F ordnance temperature was below that reported by Porter[1] at the Yuma Proving Grounds, and the calculated results from the 1964 measurements at NAD/Hawthorne (see Appendix A).

Figures B-5 and B-6 examine the maximum day. As seen in Figure B-4, while the top layer of the ordnance was momentarily subjected to 113°F the bottom of the load was never warmer than 90°F. The load in between was subjected to the gradient between these two extremes. The air under the boxcar rose to only 96°F during the day. The upper layer of ordnance reached peak temperature at 1600, then cooled off rapidly as the sun went down. The solar noon on 30 August 1965 occurred at 1240 Pacific Daylight Time. The time or soaking lag is, therefore, about three hours from peak solar insolation until peak ordnance temperature. The outside air temperature under the boxcar peaked at 1700, or a delay of four hours. The volume-limited load's top layer changed temperature from 85°F at 0800 to 113°F at 1600 for a total temperature change of 28°F.

Figure B-6 shows the temperatures for the weight-limited load. Because of the large density of the bombs, the temperature change at the bottom of the load was less than the corresponding temperature of the volume-limited load. The top of the weight-limited load remained relatively cool during the day of 30 August 1965. The thermal gradients ranged from a minimum of 0°F at 0700 to a maximum of 99° - 87°F, or 12°F. The top-of-load trace of Figure B-6 resembles the outside air temperature trace, the difference being magnitude and hour of maximum temperature.

A look at Figures B-7 and B-8 will point up the importance of a temperature soaking condition in exhibiting the maximum ordnance temperature. Figure B-7 is the plot of the maximum daily temperature readings of both the hottest and coolest points in the volume-limited load. The line between these points suggests that the entire load reached a temperature between these two values. As can be seen, the average maximum temperature throughout the load varied from 7° to 26°F. The lesser spread of maximum temperature was experienced during periods of low thermal pressure, and the greater spread during periods of higher thermal pressure.

Figure B-8 is the equivalent plot for the weight-limited situation. In contrast, the minimum and maximum spread of temperature maximums is 3 to 12°F. A comparison of Figures B-7 and B-8 indicates the effect of density in stabilizing the temperature fluctuations of an ordnance load. The weight-limited load shows gradual temperature maximum increases and decreases, with few drastic changes. The volume-limited load exhibits more violent changes in less time. This is caused by the lower density of the load. The weight-limited load, however, is more sensitive to outside air temperature extremes than is the volume-limited load. Notice, Figure B-8, that the maximum ordnance temperature was reached on 9 and 10 August 1965. The volume-limited load did not peak until much later in the series (Figure B-7).

Air temperature, as measured under the boxcar (Figure B-9), also was at the summer peak during 9 and 10 August. A comparison of Figures B-8 and B-9 indicates that ambient air temperature, to a large extent, dictates the weight-limited load's maximum temperatures.

Figure B-10 shows the solar radiation as measured at NWC, China Lake. These data are reported to the U.S. Weather Bureau under the code name Inyokern. The high temperature days of 9 and 10 August 1965 for the weight-limited load occurred when the solar radiation was not as intense as had been exhibited in the preceding period. This can be explained in large part by the relation between hot ambient air and high measured solar insolation. (In general, if the sun's energy is used to heat up the ambient air it is not available to heat up the ordnance.) The preceding days, 31 July through 7 August 1965, had displayed extremely high solar insolation. The comparative relationships for this period are shown below:

Date	Solar radiation, Langleys/day	Possible radiation Langleys/day	% of possible
31 July	795	961	83
1 Aug	804	858	84
2 Aug	848	956	89
3 Aug	847	953	89
4 Aug	843	950	89
5 Aug	844	947	89
6 Aug	822	944	88
7 Aug	831	941	88

Extreme solar insolation causes the ground temperature to rise during a typical desert clear air, low humidity condition. Add to this a high humidity condition, and the sun and hot desert now combine to heat up the air. Thus, the air transferred its available heat to the boxcar bottom and cooler sides and the normally cool, low to the floor ordnance was heated. It should be noted that desert conditions must be just right to produce temperatures above 110°F in a closed chamber such as a boxcar.

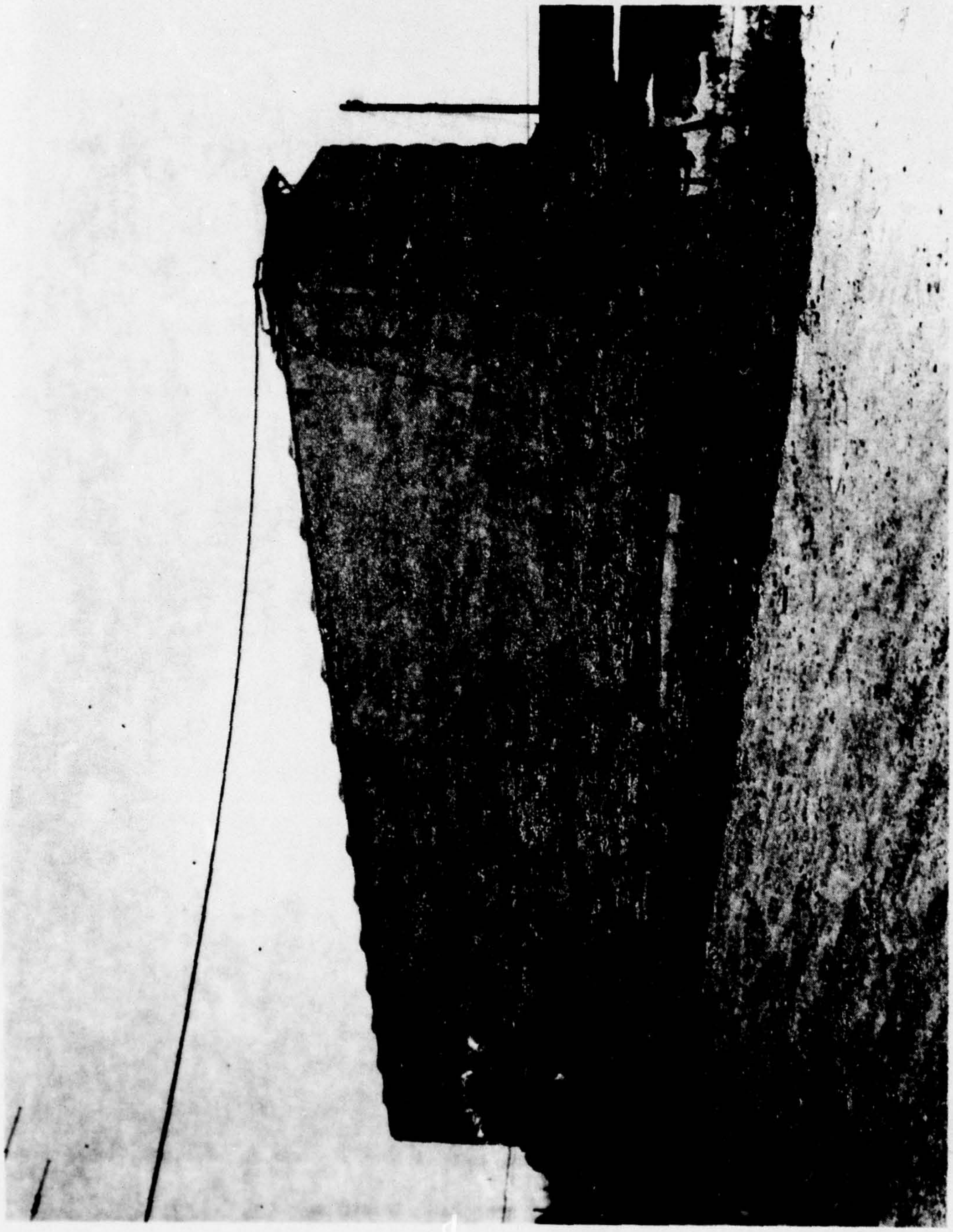


FIGURE B-1. Boxcar Duplicating Both Weight- and Volume-Limited Loads.

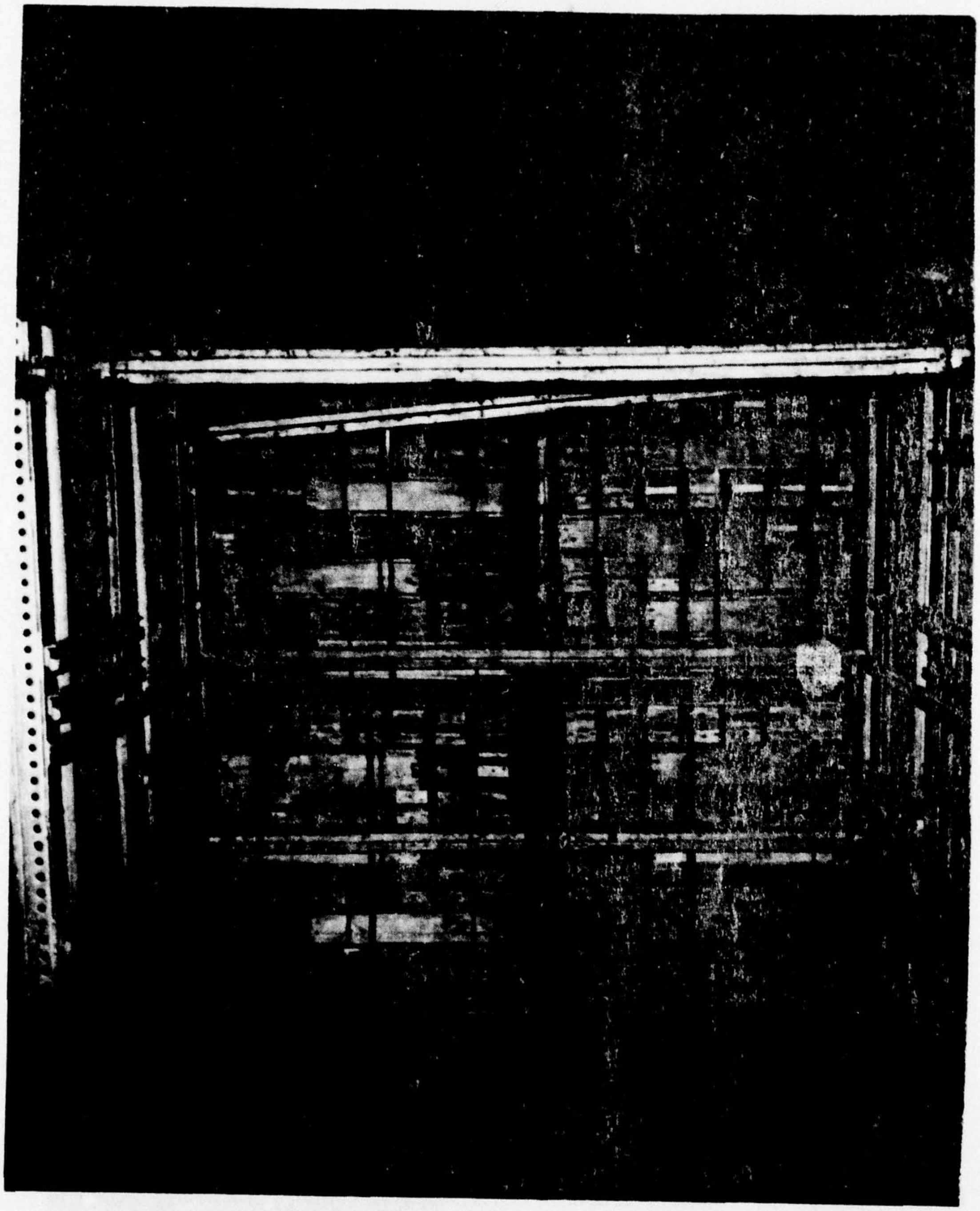


FIGURE B-2. Boxcar With Volume-Limited Loads (Zuni Warheads).

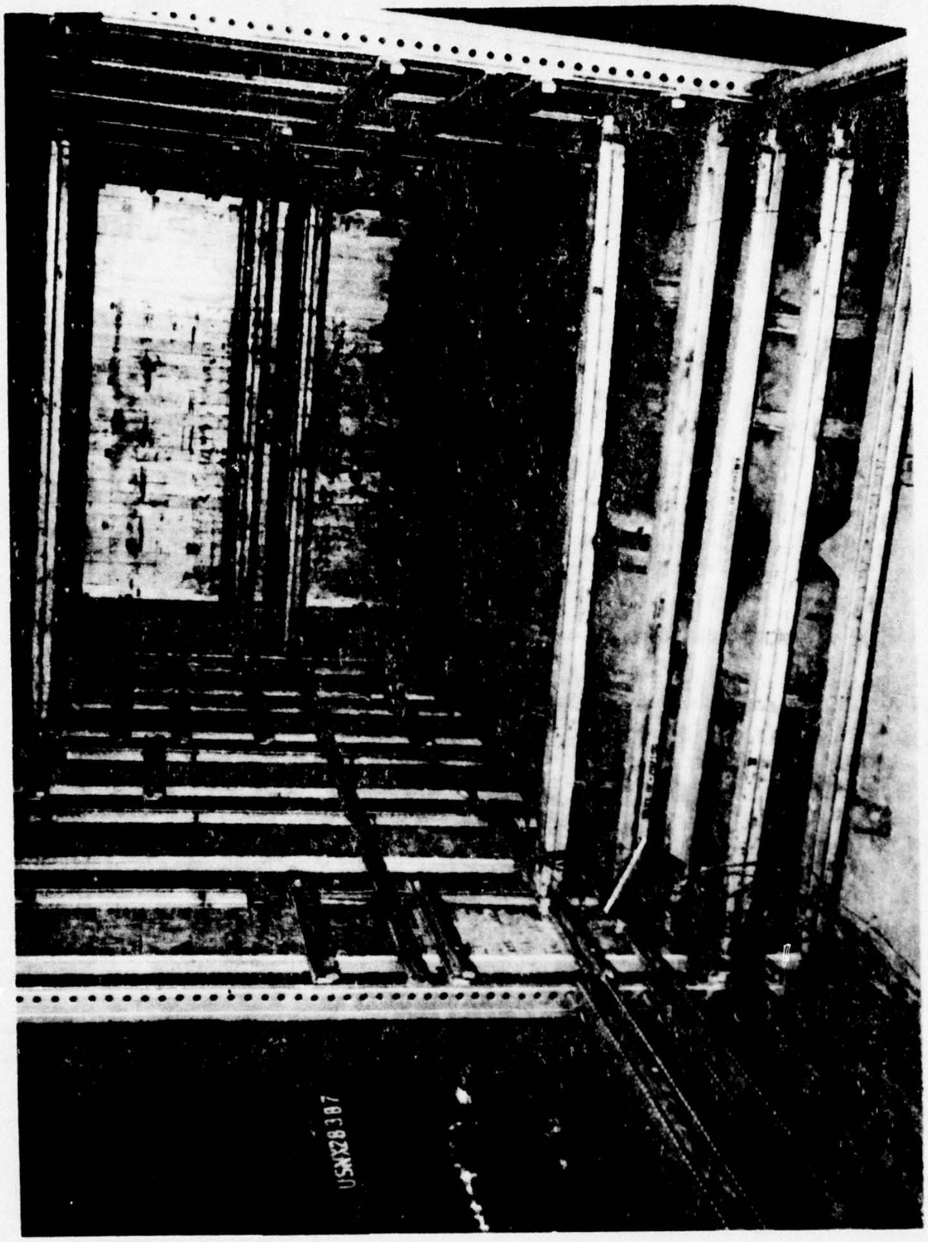


FIGURE B-3. Boxcar With Weight-Limited Load (M65A1 Aerial Bombs).

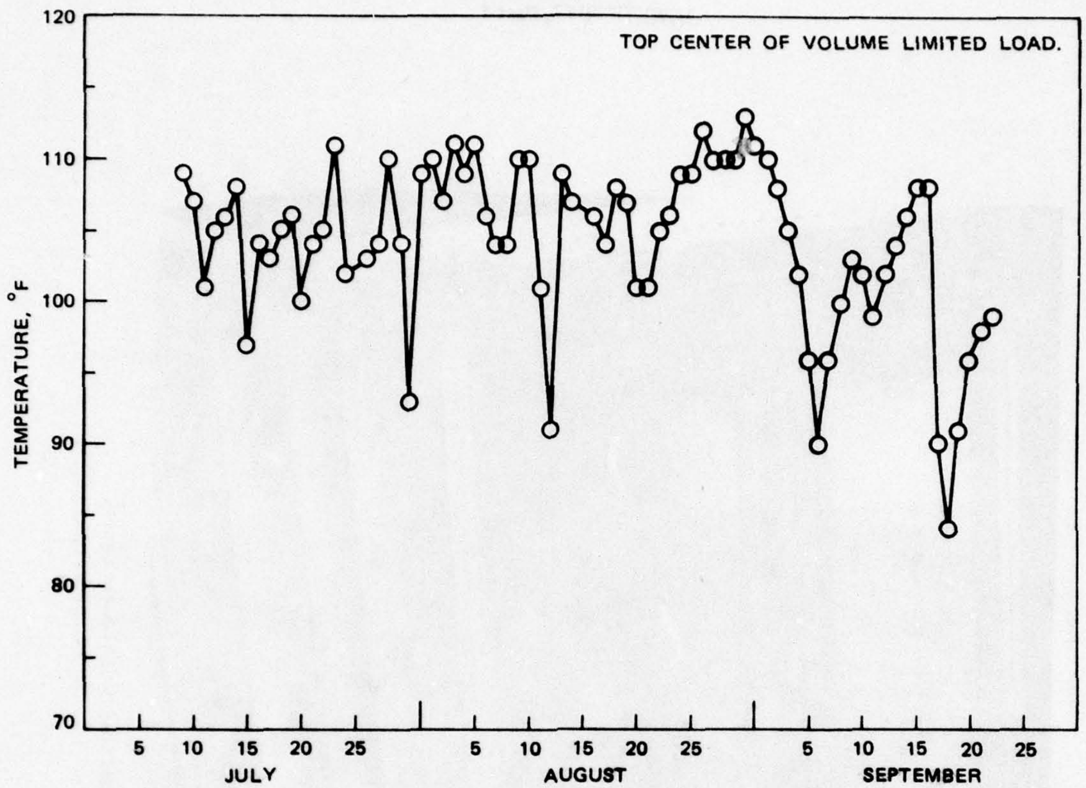


FIGURE B-4. Maximum Temperatures for Volume-Limited Load.

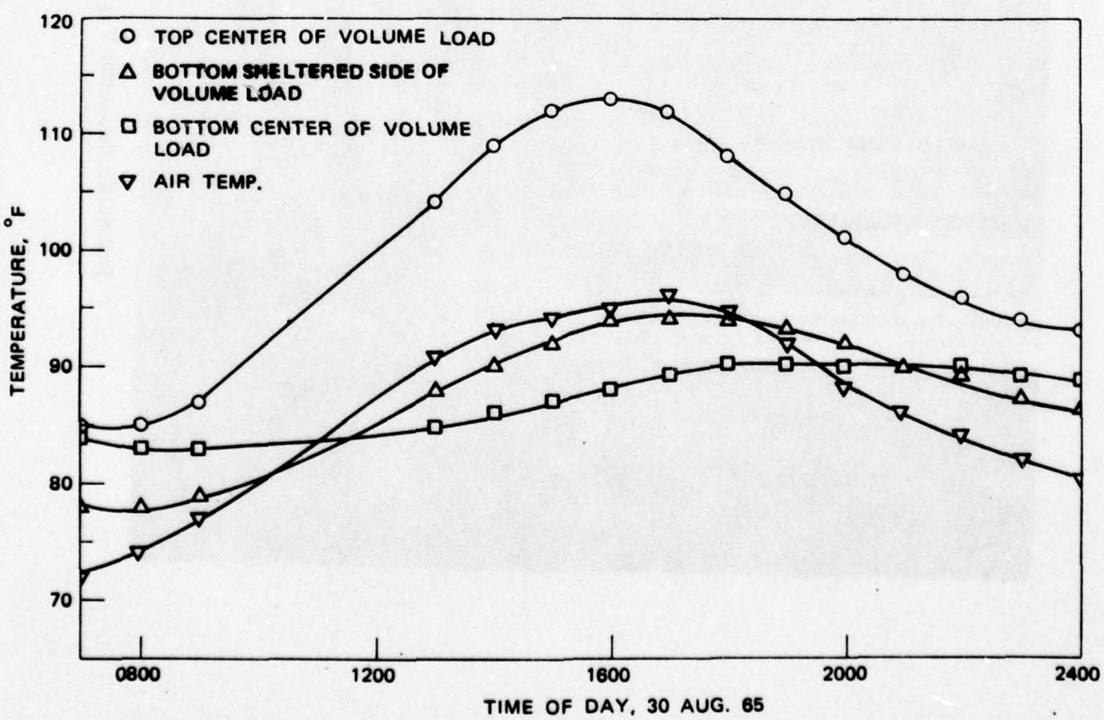


FIGURE B-5. Temperature Range for Volume-Limited Load.

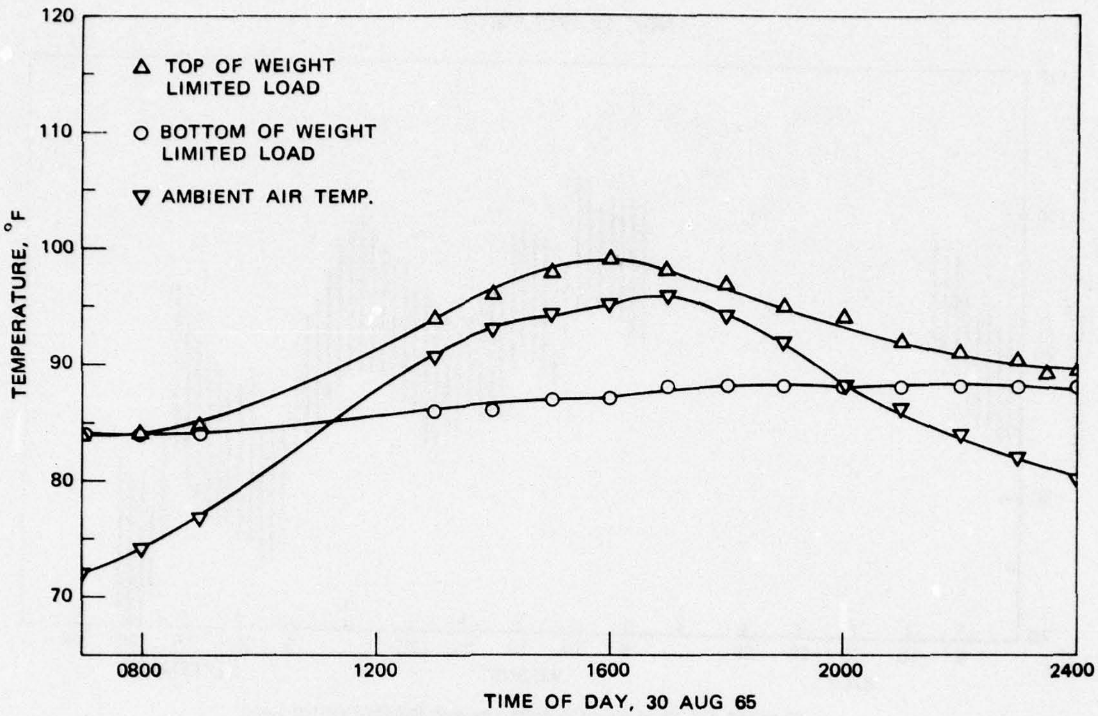


FIGURE B-6. Temperature Range for Weight-Limited Load.

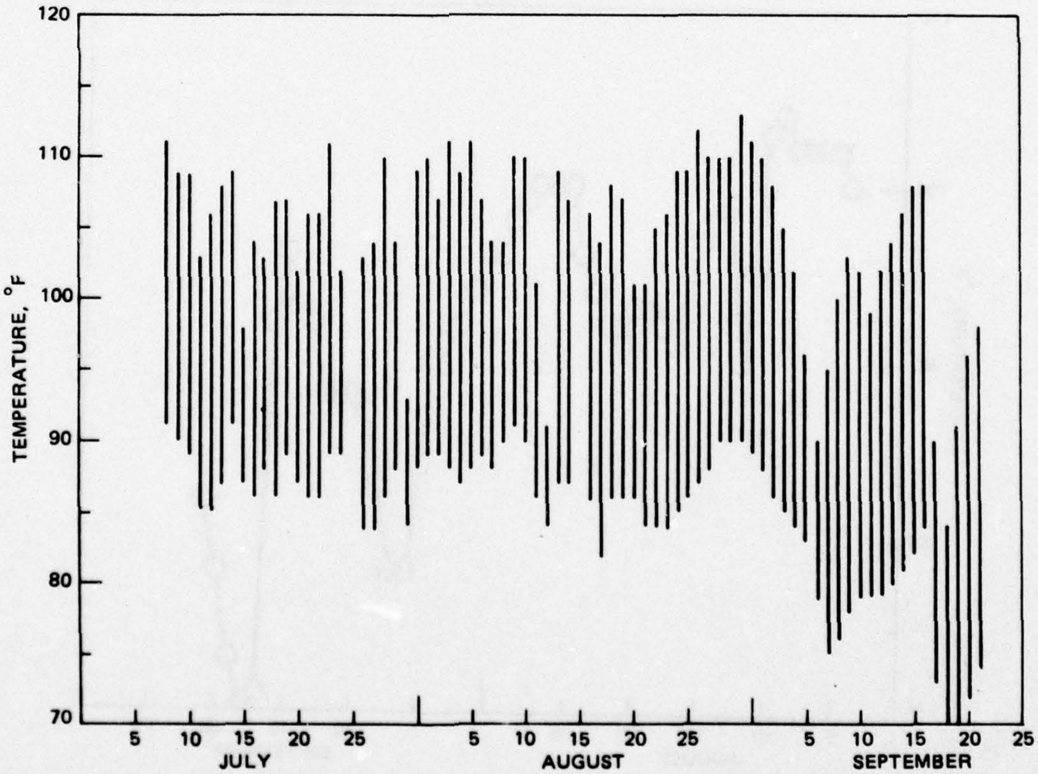


FIGURE B-7. Maximum Gradient Through the Volume-Limited Load.

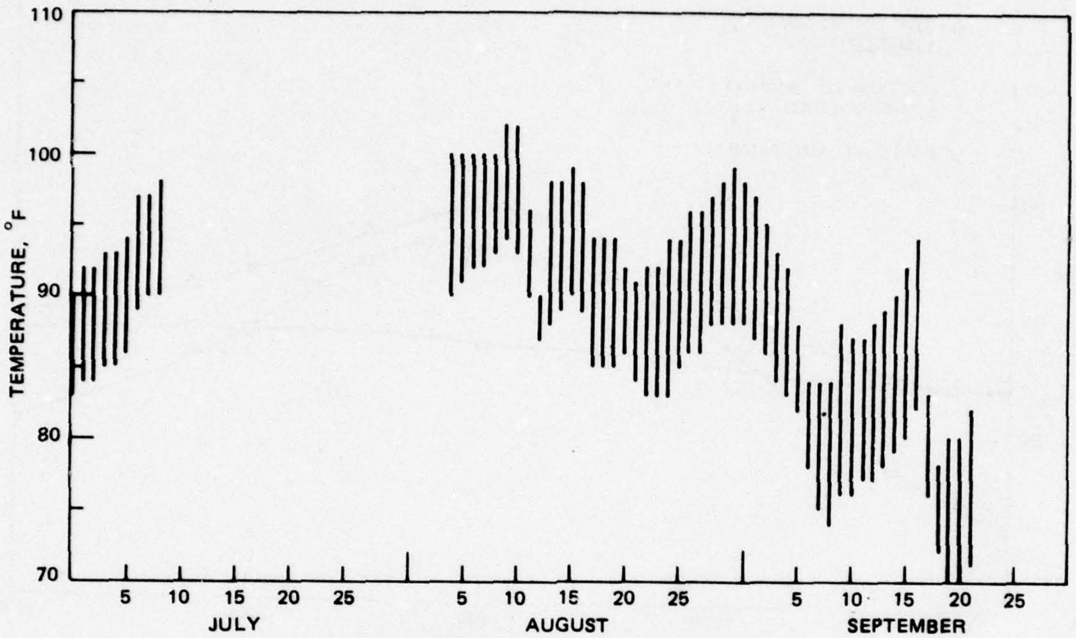


FIGURE B-8. Maximum Gradient Through Weight-Limited Load.

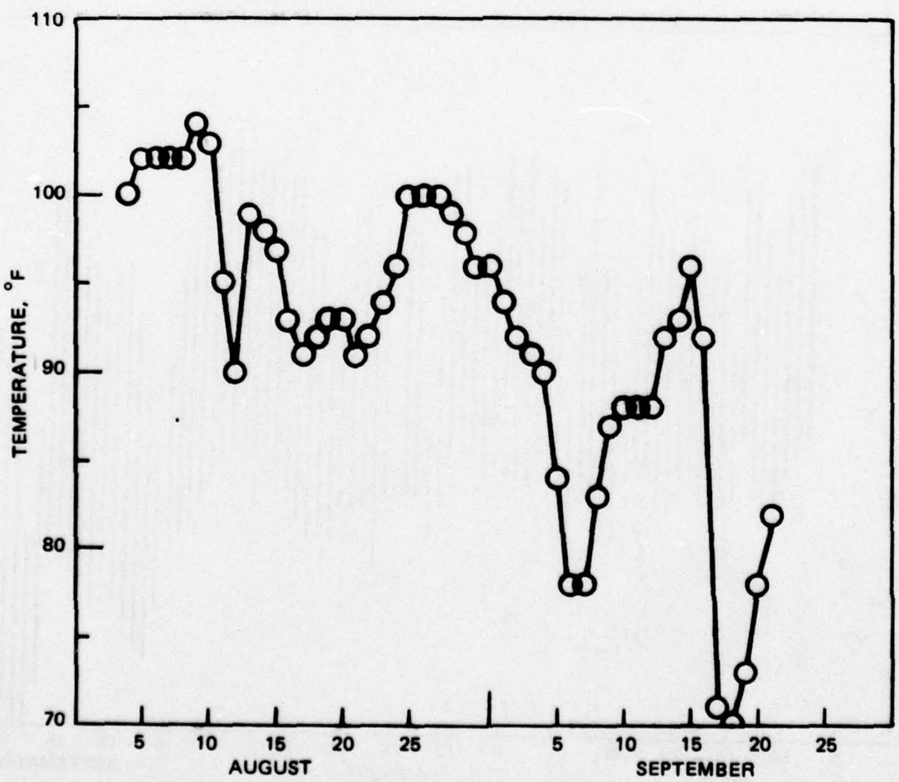


FIGURE B-9. Outside Air Temperature Under Boxcar.

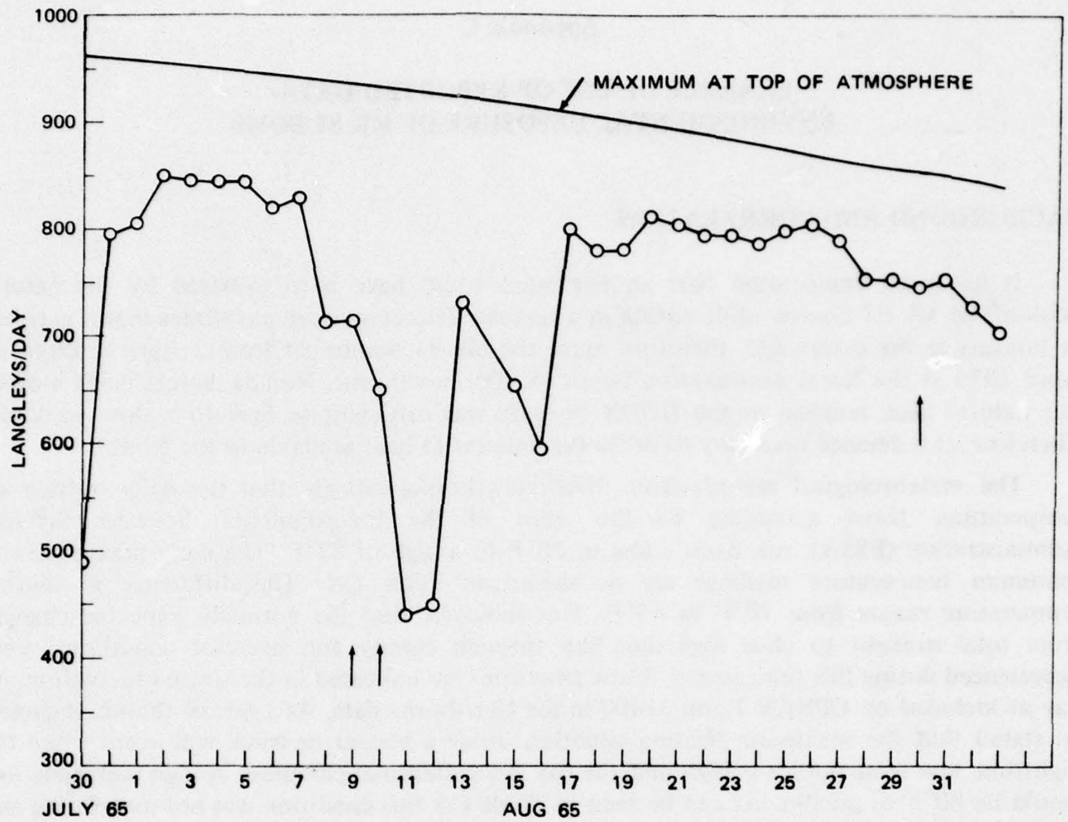


FIGURE B-10. Solar Radiation at NWC, China Lake.

Appendix C

EXAMPLE OF USE OF REPORTED DATA: ENVIRONMENTAL EXPOSURE OF MK 81 BOMB

BACKGROUND AND CORRELATION

It has been conjectured that an explosion could have been initiated by the natural cook-off of Mk 81 bombs while sitting in a boxcar. The conjecture postulates that it gets hot in boxcars in the desert and, therefore, since the Mk 81 bombs sat from 2 April through 26 April 1973 at the Naval Ammunition Depot (NAD), Hawthorne, Nevada, before being moved, the natural heat buildup in the DODX boxcars was sufficient to lead to a slow cook-off. Therefore, it is deemed necessary to detail the amount of heat available to the bombs.

The meteorological records from NAD/Hawthorne indicate that the daily outside air temperature, taken according to the rules of the Environmental Sciences Services Administration (ESSA), run from a low of 28°F to a high of 83°F. The daily maximum and minimum temperature readings are as shown in Table C-1. The difference in diurnal temperature ranges from 10°F to 45°F. This indicates that the normally expected changes from total sunlight to clear nighttime sky through cloudy and overcast conditions, were experienced during this time period. These situations are indicated in the single observation per day as included on OPNAV Form 31407 in the Hawthorne data. As a rule of thumb, it should be stated that the maximum heating situation inside a boxcar or truck will occur when the nighttime low temperature is high and the day is windless and cloudless. A high nighttime low would be 80°F or greater. As can be seen in Table C-1 this condition was not met during any one of the inclusive days of interest.

The question of interest is not how hot the ambient air was, but how hot did the Mk 81 bombs get during the period of interest. This can be answered to a high degree of accuracy if we correlate the meteorological conditions at Hawthorne, Nevada (Table C-1) with those at China Lake, California. At China Lake, the Naval Air Systems Command (AIR-03) maintains an Environmental Criteria Determination Measurement Site to determine the military exposure context of air-launched ordnance. At this site, there has been a USNX boxcar loaded with bombs, thermocoupled and exposed, since 1970. If it can be shown that the physical exposure is equivalent at the two sites (Hawthorne and China Lake), and that the meteorology is at least as severe at China Lake for the period of interest, then conclusions can be drawn.

The first step is to provide data for China Lake similar to Table C-1. As can be seen in a comparison of Tables C-1 and C-2, the Table C-2 maximum values of air temperature are consistently higher. This is to be expected since NAD/Hawthorne is farther north than China Lake and, also, about one-half mile higher in elevation. Both of these facts tend to work against maximum heating of ordnance either in or out of a boxcar.

Since the Table C-1 and C-2 comparison establishes that China Lake is in fact more conducive to high meteorological air temperatures, we can then proceed on the assumption that the ordnance temperature measured under equivalent physical situations will be at least as or more severe at China Lake when compared to NAD/Hawthorne. (If in any doubt as to the

TABLE C-1. Minimum-Maximum Temperature NAD/Hawthorne, 2-26 April 1973.

Month	Temperature, °F		
April	Minimum	Maximum	Δt
2	39	49	10
3	36	60	24
4	33	65	32
5	33	78	45
6	41	76	35
7	41	57	16
8	28	69	41
9	36	76	40
10	54	75	21
11	41	78	37
12	41	71	30
13	50	62	22
14	36	59	23
15	38	61	23
16	34	67	33
17	44	68	24
18	38	57	19
19	39	50	11
20	38	54	16
21	46	60	14
22	33	72	39
23	50	73	23
24	42	70	28
25	36	78	42
26	42	83	41

TABLE C-2. Minimum-Maximum Temperature NWC China Lake, 2-26 April 1973.

Month	Temperature, °F		
April	Minimum	Maximum	Δt
2	41	64	23
3	49	69	20
4	44	70	26
5	34	78	34
6	41	84	43
7	45	76	21
8	36	71	35
9	37	77	40
10	43	80	37
11	44	85	41
12	45	83	38
13	51	71	20
14	45	70	25
15	42	73	31
16	40	79	39
17	47	78	31
18	47	69	22
19	39	69	30
20	39	69	30
21	45	73	28
22	50	78	28
23	45	84	39
24	48	86	38
25	51	87	36
26	51	91	40

factuality of the above statement, the reader is invited to thermally integrate the solar radiation, wind velocity, and ambient air temperature profiles for the two stations in the proper meteorological context. Though more complex than the simplified method herein presented, it is also more accurate.)

CHINA LAKE MEASUREMENTS

At the Environmental Criteria Determination Measurement Site there are many different measurement matrices. The site is organized around the events of the stockpile-to-target sequence of air launched ordnance. In general, these events are transportation, storage, and airfield ready service or "hot line" exposure. (The complete details and philosophy can be found in NWC TP 4464, Part 1, and NWC TP 5039, Parts 1, 2, 3.)[3,4] The transportation portion of the exposure encompasses both open and van truck piggy-back and boxcar rail exposures.

The exposed ordnance includes all types of bombs (from 100 pounds through 1,000 pounds), rockets, fuses, warheads, and small arms. The instrumentation consists of one 200 channel thermal data logger and eight 24 channel Honeywell Universal temperature recorders. Over 200 points are thermally monitored each one-half hour continually, and have been since 1970. Therefore, it can be seen that a statistically infinite number of data points exist for most items so exposed and monitored. In the case of the bombs in the boxcar, the year to year variance is such that the three years of measurement preceding 1973 can also be judged statistically infinite.

PLACEMENT OF THERMOCOUPLES

The thermocouples were placed throughout the load of bombs in the boxcar at China Lake as follows:

97: Skin of bottom bomb, NW corner.
98: Center of top bomb, center of bomb load.
99: Skin of top bomb, center of bomb load.
100: Air temperature in car, 6 inches from ceiling.
101: Ambient air temperature in boxcar.
102: Skin of top bomb, east side of bomb load.

It must be remembered that a boxcar can carry a volume greater than its weight capacity of bombs would allow. Therefore, we can treat the load of bombs as a weight-limited load. Therefore, all the bombs are very close to the floor of the boxcar. Hot air rises and the sun beats down on the upper portions of the boxcar. Therefore, it can be seen that the top of the load would tend to be exposed to more extreme temperatures than the bottom of the load.

[3] Naval Weapons Center. *Environmental Criteria Determination for Air-Launched Tactical Propulsion Systems. Part 1. Stockpile-to-Target Sequence*, by Howard C. Schafer. China Lake, Calif., NWC, July 1968. (NWC TP 4464, Part 1, publication UNCLASSIFIED.)

[4] Naval Weapons Center. *Measured Temperatures of Solid Rocket Motors Dump Stored in the Tropics and Desert. Part 1, Discussion and Results; Part 2, Data Sample; Part 3, Desert Storage*, by H.C. Schafer. China Lake, Calif., NWC, November 1972 (Parts 1 and 2) and May 1977 (Part 3).(NWC TP 5039, Parts 1, 2, and 3, publication UNCLASSIFIED.)

The thermocouple that will yield the most meaningful information, of those available is the one identified as channel 99, skin of top bomb in the center of the bomb load. The reason this is the most meaningful is that it will yield the best information available as to the "bulk" temperature of the bomb load. (The other channels were reviewed and are available from the Naval Weapons Center, China Lake.) The bulk temperature is herein defined as the temperature used by the physical chemist to calculate cook-off potential and time to cook-off. Table C-3 is the complete printout for the month of April 1973 for channel 99, center bomb skin. As can be seen in the minimum column, the bombs indicated a minimum skin temperature of 52°F and a high minimum, skin temperature of 74°F for the days of interest. The average minimum temperature is shown as 63.9°F for the month. The maximum skin temperature is 88°F with a low maximum skin temperature of 61°F. The average maximum bomb skin temperature is shown as 74.4°F. For calculations, the best single number to use for the time period in question would be halfway between 74.4°F and 63.9°F, which is 69.2°F, or for normal work 70°F.

Reaction kinetic calculations for Tritonal indicate a time-to-cook off at 70°F to be on a geologic scale (greater than 100,000 years) not within the 26 days available in the context of this problem.

CUMULATIVE PROBABILITY

It may be desirable to put the month of April 1973 into a more broad context. It can be shown that statistically the 70°F average bulk temperature exhibited for April 1973 is not a high temperature in the context of the yearly cycle for a desert exposure. Figure C-1 is the cumulative probability plot for the channel 99 information from 1 April 1971 through 30 April 1973. It is made up of 17,772 individual hourly temperature reports from the channel 99 bomb skin measurement. It must be kept in mind that there are a nominal 8,760 hours per year for a non-leap year. Also, it must be remembered that these data are for a nonmoving boxcar and from the skin of a bomb, not its interior.

Figure C-1 is the accumulation of hours at a given temperature in ascending numerical order. For example, all the hours preceding 70°F are added to the number of hours at 70°F and then divided by the total hours in the sample (17,772). This gives a nominal 0.5 value for 70°F. This can be read as 50% of the time the skin of the bomb is at a temperature of 70°F or less. Conversely, 50% of the time during the yearly cycle, the skin of the bomb is at a temperature of 70°F or more.

From Figure C-1 it can be seen that the highest bomb skin temperature reported to channel 99 in two years is 116°F. It must be remembered that at NAD/Hawthorne, even in the heat of the summer, the ordnance exposed in a similar manner would not experience more extreme conditions.

TABLE C-3. Hourly Temperatures of Boxcar Stored Bombs in the Desert.

RAILROAD BOXCAR WITH 1000 POUND BOMBS CHANNEL 99

SKIN OF TOP BOMB IN CENTER OF BOMB LOAD

YEAR IS 1973. MONTH IS 4.

FIRST COLUMN IS DAY OF MONTH AND EACH SUCCEEDING COLUMN IS TEMPERATURE IN DEGREES FAHRENHEIT AT HOUR WHICH IS DESIGNATED AT TOP OF COLUMN. THE LAST TWO COLUMNS GIVE THE MINIMUM AND MAXIMUM TEMPERATURE FOR THE DAY.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	MIN	MAX
1	60	60	59	57	57	58	55	57	57	58	58	59	60	61	61	61	61	59	59	58	58	58	56	57	55	61
2	57	55	55	55	52	52	54	52	55	56	57	58	58	59	60	61	59	60	60	59	59	57	58	56	52	61
3	56	57	57	56	56	56	56	56	57	60	61	61	63	64	65	65	65	63	63	62	62	61	61	61	56	65
4	61	60	60	59	59	58	57	58	60	60	62	63	64	64	65	65	65	65	65	63	62	62	60	61	57	65
5	60	58	57	57	57	55	55	57	58	61	62	66	67	69	70	71	71	70	70	67	67	66	63	63	55	71
6	63	61	60	61	60	60	58	59	61	66	67	70	73	74	75	76	76	75	74	73	72	71	70	70	58	76
7	70	68	67	68	66	65	65	67	69	70	72	73	75	75	75	74	74	73	73	72	71	70	69	68	65	75
8	67	66	63	62	64	62	62	63	66	68	69	70	72	72	73	73	73	73	72	70	70	68	67	67	62	73
9	66	65	63	63	62	61	61	61	62	65	68	70	71	72	73	72	71	71	71	70	70	69	68	68	61	73
10	67	66	66	65	63	62	62	62	66	66	69	71	72	73	74	75	75	74	73	72	71	71	70	70	62	75
11	69	68	67	67	66	66	65	66	68	70	73	74	76	77	78	78	78	78	77	76	75	74	73	72	65	78
12	72	71	70	69	70	69	69	69	70	73	75	77	78	78	78	78	77	77	76	74	73	73	72	72	69	78
13	71	71	71	70	69	69	68	70	69	69	71	72	73	73	73	73	73	71	70	69	67	67	66	67	66	73
14	66	64	64	65	63	62	61	62	64	66	68	70	71	72	72	72	72	72	71	70	69	67	67	66	61	72
15	65	64	63	62	61	61	61	61	62	63	67	69	70	70	70	70	70	70	69	68	67	66	65	65	61	70
16	63	63	62	61	61	61	61	61	63	66	69	70	71	72	72	72	72	72	71	70	70	69	68	68	61	72
17	67	67	66	66	65	65	63	65	67	69	71	72	73	72	71	71	71	71	70	69	68	68	67	66	63	73
18	66	65	65	63	63	62	62	62	64	66	68	69	70	70	71	71	71	71	70	69	68	67	66	65	62	71
19	65	63	63	62	62	61	61	62	65	66	68	70	71	71	71	71	70	69	68	67	66	65	65	64	61	71
20	63	62	62	61	61	60	60	61	61	62	64	66	67	68	69	69	69	69	68	67	66	65	64	63	60	69
21	63	62	62	61	61	60	60	61	63	66	67	69	70	71	72	72	72	72	71	70	69	69	68	67	60	72
22	67	66	66	65	65	64	64	65	67	69	71	72	74	74	76	76	76	76	75	74	73	71	71	70	64	76
23	70	70	67	68	67	67	67	68	70	71	73	75	76	77	78	79	80	80	79	78	77	76	75	74	67	80
24	73	73	72	71	70	70	70	71	73	75	77	78	80	81	82	83	83	83	82	81	80	78	78	77	70	83
25	76	75	75	74	73	73	73	73	75	77	79	81	82	84	85	85	85	85	84	82	82	81	80	79	73	85
26	78	77	76	76	75	74	74	75	78	80	81	83	84	85	85	87	87	87	86	85	83	81	82	80	74	87
27	80	79	78	78	77	75	77	77	78	79	82	85	86	87	87	88	88	87	86	84	84	63	82	81	75	88
28	81	79	80	79	78	78	78	79	81	82	84	85	85	85	86	86	85	85	84	83	82	82	81	80	78	86
29	79	78	75	76	75	76	74	75	74	76	78	79	80	79	80	80	78	79	78	77	76	74	74	73	73	80
30	73	73	71	71	70	70	70	70	71	73	73	73	73	74	74	74	74	73	73	73	72	71	71	70	70	74

MEAN MINIMUM TEMPERATURE IS 63.9 STANDARD DEVIATION IS 6.53
MEAN MAXIMUM TEMPERATURE IS 74.4 STANDARD DEVIATION IS 6.96

THORNE TO ROSEVILLE

The preceding has addressed the thermal excursion while the Mk 81 bomb laden boxcars were awaiting movement at Thorne, Nevada. As soon as the Southern Pacific Transportation Company took charge of these boxcars the mode of heat transfer immediately changed. When a boxcar is moving with respect to the ambient air at more than 5 miles per hour then the chance of having a maximum thermal exposure from natural means diminishes. Also at that time a cold front was in the process of sweeping the northwest section of the country. The meteorological records for Reno and Hawthorne indicate a progressive cooling trend starting on 26 April 1973 until the end of the month. While the boxcars were in or near Sparks, Nevada, Reno was experiencing maximum temperatures of only 78°F with nighttime low temperatures of 30°F. The velocity of the train as it progressed from Thorne, Nevada, to Sparks and into the Sierra Nevada Mountain Range is from a warmer to a cooler climate. The movement of the train tends to cool the boxcars to the temperature of the outside ambient air by convection. In simple terms the trip from NAD/Hawthorne to Roseville, California, where the explosion occurred, could only have provided the Mk 81 bombs with a progressively cooler meteorological regime.

SUMMARY

As far as the incident at Roseville is concerned, it can be firmly stated that the springtime weather experienced from 2 through 28 April 1973 had nothing to do with any alleged "self heating" or cook-off of the Mk 81 bombs. The maximum probable bomb case temperature in this time frame from natural weather causes did not exceed 87°F, and even this for no more than three hours on only one day. After the train started to move convection cooling became a potent force assuring that the bombs would assume a temperature closer to that of the outside air. Therefore on the trip from Thorne to Roseville, the bombs experienced no natural heating circumstances outside of the accepted "room temperature" values.

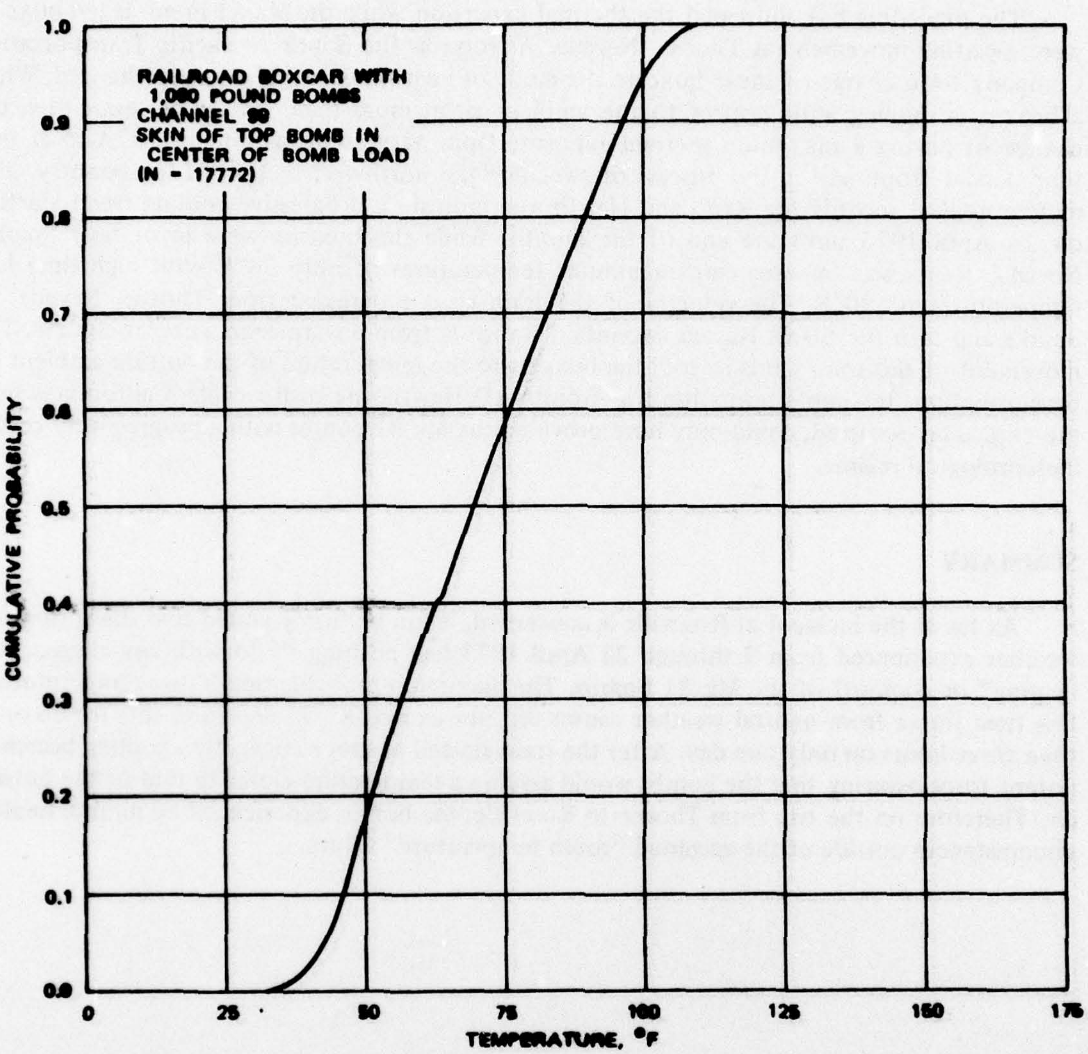


FIGURE C-1. Cumulative Probability Curve for Railroad Boxcar Loaded With 1,000-Pound Bombs.

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- ENA (1)
- ENE (1)
- ENF (1)
- ENS (1)
- FEE (3)
- PP (1)
- RTSAW (1)
- SD (1)
- SD25 (1)
- SD65 (1)
- YF (1)
- YFL (1)
- YFT (1)
- YP (1)
- YPL (1)
- YPT (1)
- YX (1)
- YXL (1)
- YXT (1)

1 Air Force Avionics Laboratory, Wright-Patterson Air Force Base

4 Air Force Cambridge Research Laboratories, Laurence G. Hanscom Field
- Code LKI
  - I. I. Gringorten (1)
  - P. Tattleman (2)
- Technical Library (1) .

3 Air Force Environmental Technical Applications Center
- Technical Director (1)
- O. E. Richards (1)
- Technical Library (1)

1 Air Force Office of Scientific Research (Dr. J. F. Masi)

1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Director)

1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Plans and Programs Office)

1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Dr. Trout)

2 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (RKMA, L. Meyer)

1 Air Force Rocket Propulsion Laboratory, Edwards Air Force Base (Technical Library)

23 Armament Development and Test Center, Eglin Air Force Base

DL (1)	DLY (1)	SD9 (1)
DLA (1)	SD (1)	SDMT
DLB (1)	SD102 (1)	Carley (1)
DLD (1)	SD15 (1)	Holcomb (1)
DLJ (1)	SD2 (1)	Volz (1)
DLM (1)	SD23 (1)	TE (2)
DLO (1)	SD3 (1)	Technical Library (1)
DL-1 (1)	SD7 (1)	

1 Nellis Air Force Base (Technical Library)
2 Rome Air Development Center, Griffiss Air Force Base
    Code RCRM (1)
    Technical Library (1)
7 Assistant Secretary of Defense
    DMSSO, J. Allen (2)
    F. W. Myers (1)
    J. A. Mittino (1)
    Explosives Safety Board (3)
7 Director of Defense Research and Engineering
    AD(ET) G. R. Makepeace (1)
    OAD(ET) R. Thorkildsen (1)
    US of D (SS), Col. B. Swett (2)
    DD(T&E) Lt. Gen. Lotz (1)
    AMRAD Committee (2)
5 Defense Advanced Research Project Agency, Arlington
    Technical Director (1)
    Strategic Tech (1)
    Tactical Tech (1)
    Tech Assessments (1)
    Technical Library (1)
12 Defense Documentation Center
7 Joints Chiefs of Staff
    Chairman Staff Group (1)
    Director J-3 (1)
    WWMCCS ADP (1)
    Standards Branch (1)
    Europe/Middle East/African Div (1)
    Director J-4 (1)
    Director J-5 (1)
3 Library of Congress
1 Aerojet-General Corporation, Azusa, CA (Technical Library)
2 Aerojet Liquid Rocket Co., Sacramento, CA (via AFPRO) (Technical Library)
1 Allegany Ballistics Laboratory, Cumberland, MD (Technical Library)
1 Applied Physics Laboratory, Johns Hopkins University, Laurel, MD (Technical Library)
1 ARINC Research Corporation, Santa Ana, CA
2 Bell Aerospace Textron, Dallas, TX
    Technical Library (1)
    D. L. Kidd (1)
1 Booze Allen, Bethesda, MD

2 Chemical Propulsion Information Agency, Applied Physics Laboratory, Laurel, MD
  Sid Solomon (1)
  Technical Library (1)
1 Cushing Neveil Incorporated of California, Los Angeles, CA
2 Dayton T. Brown, Inc., Bohemia LI, NY
  Technical Library (1)
  F. Gerber (1)
2 Ford Aerospace and Communications Corporation, Newport Beach, CA
  R. Elston (1)
  Technical Library (1)
1 General Dynamics, Pomona Division, Pomona, CA (Technical Library)
1 Hercules, Inc., Bacchus Works, Magna, UT
1 Hercules, Inc., McGregor, TX (Technical Library)
2 Hughes Aircraft Company, Canoga Park, CA
  C. Clapp (1)
  Technical Library (1)
1 Institute for Defense Analyses, Arlington, VA (Technical Library)
2 Institute of Environmental Sciences, Mt. Prospect, IL
2 Lockheed Aircraft Corporation, Marietta, GA
  Technical Library (1)
  E. H. Parker (1)
1 Lockheed-California Company, Burbank, CA
1 McDonnell Douglas Astronautics, Huntington Beach, CA
2 McDonnell Douglas Corporation, Long Beach, CA
  PABST Program Office (1)
  Technical Library (1)
1 McDonnell Douglas Corporation, Santa Monica, CA
7 McDonnell Douglas Corporation, St. Louis, MO
  Aircraft Division, Technical Library (1)
  Harpoon Project Office (1)
  Missile Division Technical Library (1)
  F-18 Program Engineering (1)
  B. Dighton (1)
  J. P. Capellupo (1)
  GIDEP Rep. (1)
1 Marquardt Corporation, Van Nuys, CA
2 Martin-Marietta Company, Denver, CO
  Reliability (1)
  Technical Library (1)
2 Martin-Marietta Corporation, Orlando, FL
  Engineering Library MP-30 (1)
  Technical Library (1)
2 North American Rockwell Corporation, Columbus, OH
  Engineering Development Laboratories (1)
  Technical Library (1)
2 Raytheon Company, Waltham, MA
  Missile Systems (1)
  Technical Library (1)

2 Rocketdyne International Corporation, Rocketdyne Division, Canoga Park, CA
    A. Kohl (1)
    Technical Library (1)
1 Rockwell International Corporation, Los Angeles, CA (Technical Library)
1 Rohm and Haas Company, Huntsville, AL
3 Sandia Corporation, Albuquerque, NM
    Section 1541, Jerry T. Foley (2)
    Section 1543, Mark B. Gens (1)
3 Sandia Corporation, Livermore, CA
    C. A. Scott (2)
    Technical Library (1)
1 Texas Instruments, Inc., Dallas, TX (Technical Library)
5 The Boeing Company, Seattle, WA
    S. Barber, MS 8609 (1)
    J. P. Stebbins (1)
    F. P. Stevens, Standards Control (1)
    J. Stuart, MS 47-06 (1)
    Technical Library (1)
1 Thiokol Chemical Corporation, Newtown, PA
1 Thiokol Chemical Corporation, Wasatch Division, Brigham City, UT
1 United Technologies, Chemical Systems Division, Sunnyvale, CA
2 Value Engineering Company, Alexandria, VA
    J. Toomey (1)
    Oxnard Plant (1)
4 Vought Corporation, Systems Division, Dallas, TX
    R. N. Hancock, Unit 2-53483 (2)
    C. T. Morrow, P.O. Box 6144 (1)
    Technical Library (1)